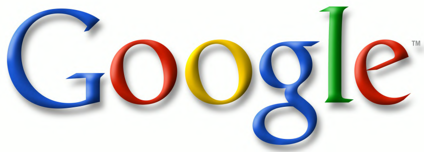
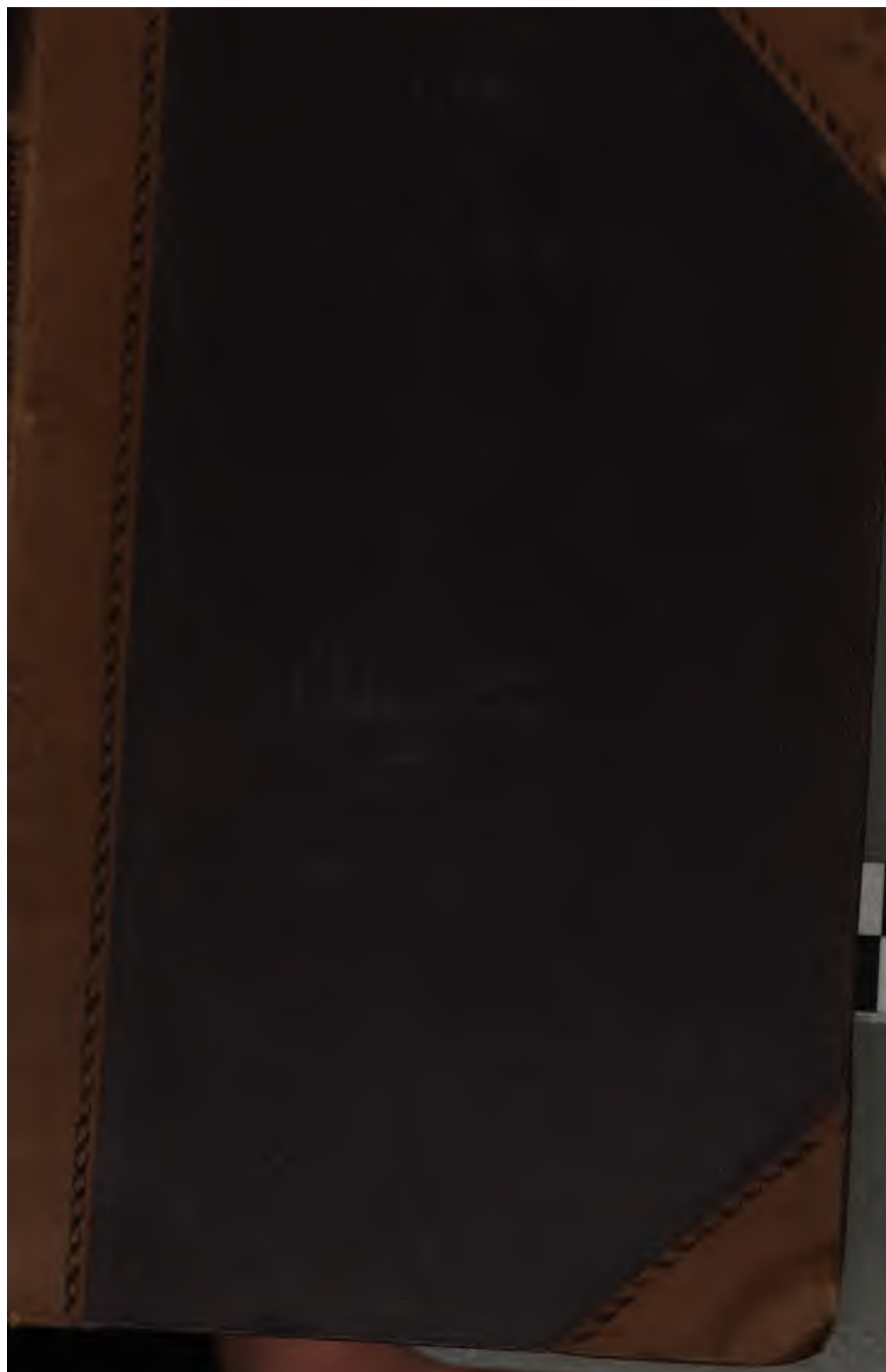
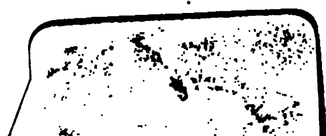
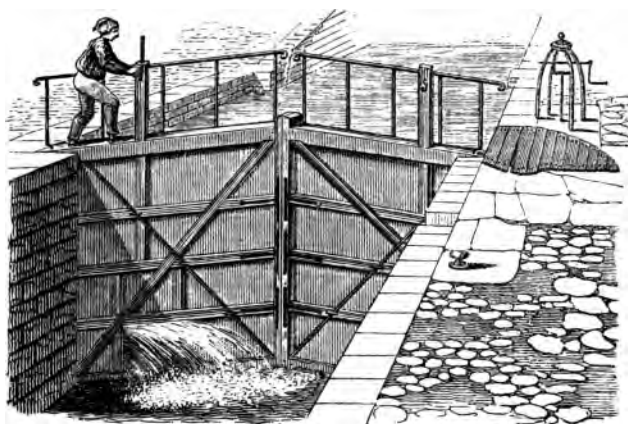
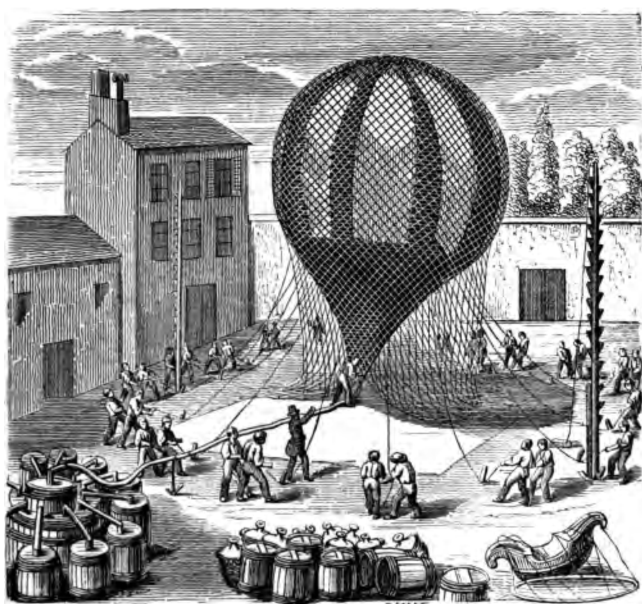












HAND-BOOK

OF

NATURAL PHILOSOPHY.

BY

DIONYSIUS LARDNER, D.C.L.

ERLY PROFESSOR OF NATURAL PHILOSOPHY AND ASTRONOMY IN UNIVERSITY COLLEGE, LONDON.

HYDROSTATICS, PNEUMATICS, AND HEAT.

WITH TWO HUNDRED AND NINETY-TWO ILLUSTRATIONS.



LONDON:

WALTON AND MABERLY,

PER GOWER STREET, AND IVY LANE, PATERNOSTER-ROW.

1855.

LONDON:
Printed by SPOTTISWOODE and Co.,
New-street-Square.

PREFACE.

THIS work is intended for all who desire to attain an accurate knowledge of Physical Science, without the profound methods of Mathematical investigation. Hence the explanations are studiously popular, and everywhere accompanied by diversified elucidations and examples, derived from common objects, wherein the principles are applied to the purposes of practical life.

It has been the Author's especial aim to supply a manual of such physical knowledge as is required by the Medical and Law Students, the Engineer, the Artisan, the superior classes in Schools, and those who, before commencing a course of Mathematical Studies, may wish to take the widest and most commanding survey of the field of inquiry upon which they are about to enter.

Great pains have been taken to render the work complete in all respects, and co-extensive with the actual state of the Sciences, according to the latest discoveries.

Although the principles are here, in the main, developed and demonstrated in ordinary and popular language, mathematical symbols are occasionally used to express results more clearly and concisely. These, however, are never employed without previous explanation.

The present edition has been augmented by the introduction of a vast number of illustrations of the application of the various branches of Physics to the Industrial Arts, and to the practical business of life. Many hundred engravings have also been added to those, already numerous, of the former edition.

For the convenience of the reader the series has been divided into Four Treatises, which may be obtained separately.

Mechanics	One Volume.
Hydrostatics, Pneumatics, and Heat .	One Volume.
Optics	One Volume.
Electricity, Magnetism, and Acoustics .	One Volume.

The Four Volumes taken together will form a complete course of Natural Philosophy, sufficient not only for the highest degree of School education, but for that numerous class of University Students who, without aspiring to the attainment of Academic honours, desire to acquire that general knowledge of these Sciences which is necessary to entitle them to graduate, and, in the present state of society, is expected in all well educated persons.

CONTENTS.

BOOK I.

Hydrostatics.

CHAPTER I.

TRANSMISSION OF PRESSURE.

CHAP. II.

THE PRESSURE OF LIQUIDS DUE TO THEIR WEIGHT.

CHAP. III.

LIQUIDS MAINTAIN THEIR LEVEL.

CHAP. IV.

SOLIDS IMMERSED IN LIQUIDS.

CHAP. V.

CAPILLARITY, ENDOSMOSE, AND ABSORPTION.

CHAP. VI.

LIQUIDS IN MOTION.

BOOK II.

Pneumatics.

CHAPTER I.

GENERAL PROPERTIES.

CHAP. II.

COMPRESSIBILITY, ELASTICITY, AND WEIGHT OF AIR.

CHAP. III.

RAREFACTION AND CONDENSATION OF AIR.

BOOK III.

Heat.

CHAPTER I.

PRELIMINARY PRINCIPLES AND DEFINITIONS.

CHAP. II.

THERMOMETRY.

CHAP. III.

DILATATION.

CHAP. IV.

CALORIMETRY.

CHAP. V.

LIQUEFACTION AND SOLIDIFICATION.

CHAP. VI.

VAPORISATION AND CONDENSATION.

CHAP. VII.

CONDUCTION.

CHAP. XI.

THE SENSATION OF HEAT.

ELEMENTARY COURSE

OF

HYDROSTATICS, PNEUMATICS, AND HEAT.

BOOK THE FIRST.

HYDROSTATICS.

CHAPTER I.

THE TRANSMISSION OF PRESSURE.

1. The liquid state has already been defined to be that in which the constituent molecules of the body manifest neither cohesion nor repulsion. They have no tendency like those of a solid to cohere, and are separated by the least force applied to them; neither have they, on the other hand, any tendency like those of gas to repel each other and fly asunder. The particles composing a mass of liquid lie in juxtaposition, each affected merely by its own gravity.

These observations would equally apply, however, to a collection of fine sand or dust, and it may therefore be asked in what respects such a mass differs from a liquid. The particles composing a liquid differ, in the first place, from those composing a mass of sand or dust in being infinitely small. A solid body can be reduced to no powder so impalpable, but that the separate grains of it may be individually contemplated and ascertained to possess all the characters of a solid body. This is not the case with the particles of a liquid which admit of unlimited subdivision, each part so divided still continuing to possess all the characters of a liquid.

But independently of this, the particles of a liquid have the further quality, in which they are distinguished from a pulverised

solid, of moving amongst each other without friction. There is no powder so fine or impalpable as to possess this property. The particles of a liquid, on the contrary, possess it in the most absolute manner.

2. From this absolute freedom of motion amongst each other, and total absence of friction, may be inferred the fact that liquids are capable of transmitting pressure equally in every direction, a quality which may be considered as the fundamental mechanical property of this class of bodies, and one from which all the circumstances attending their mechanical phenomena will follow.

To explain this property, let a vessel, A B C D E F (*fig.* 1.), of any form whatever, be filled with a liquid which we shall suppose for the present to be divested of weight.

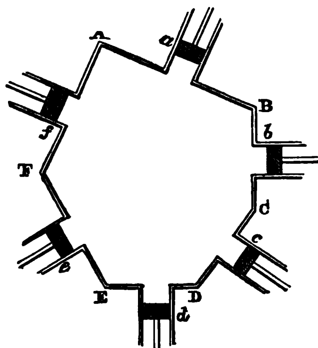


Fig. 1.

Let a small circular aperture, having the magnitude of a square inch, be made in each of its sides at *a*, *b*, *c*, *d*, *e*, *f*, and let a small cylinder be imagined to be inserted in each of these apertures, in which a piston is fitted, so as to be in contact with the liquid, and so that the liquid shall not pass between it and the cylinder.

As we have supposed the liquid itself to be divested of weight, it will have no tendency to press any of the pistons outwards. Now, if any pressure whatever, as, for example, one pound weight, on the piston *a*, force it inwards, it will be found that all the other pistons, *b*, *c*, *d*, *e*, *f*, will immediately be forced outwards, and that the force necessary to resist this tendency would be one pound; so that when the piston *a* is pressed inwards with a force of one pound, it would be necessary to apply a like force pressing inwards to each of the other pistons to keep them in their places. It follows from this, that a pressure of one pound applied at *a* exerts a corresponding pressure of one pound against the inner surface of each of the pistons *b*, *c*, *d*, *e*, *f*. But the same would be true whatever positions the pistons *b*, *c*, *d*, *e*, *f* might have; and it follows, therefore, that a pressure of one pound exerted upon the square inch of surface forming the base of the piston *a*, will produce a pressure of one pound upon every square inch of the interior of the surface of the vessel containing the liquid.

This property of transmitting pressure equally and freely in

every direction, is one in virtue of which a liquid becomes, in the strictest sense of the term, a machine.

3. **Hydrostatic paradox.** — Some of the effects which are consequent upon it are so surprising and unexpected that they have acquired for it the generally known title of the *hydrostatic paradox*. There is, however, in this effect nothing more deserving of the title of paradox than is to be found in all machinery.

One of the forms under which the hydrostatic paradox is commonly presented is the following. Let A B C D (*fig.* 2.) be a close vessel filled with water. Let O be a cylinder, having in it a piston, P, the area of whose base is one square inch; and let O′ be another cylinder having in it a piston P′, the area of whose base is 1000 square inches. According to what has been stated, a pressure of 1 lb. acting on the piston P, will produce an outward pressure of 1000 lbs. acting on the piston P′, so that a weight of 1 lb. resting upon the piston P would support a weight of 1000 lbs. resting upon the piston P′. Now, if the piston P be moved downwards with a force of 1 lb., the piston P′, loaded with 1000 lbs., would be raised.

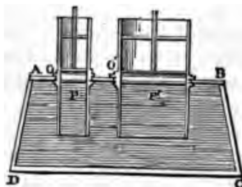


Fig. 2.

There is, nevertheless, in these facts, nothing contrary to what might be inferred from the common principles already explained as governing the effects of mechanical force. The action of the forces here supposed differs in nothing from that of like forces acting on a lever having unequal arms in the proportion of 1 to 1000. A weight of 1 lb. acting on the longer arm of such a lever would support or raise a weight of 1000 lbs. acting on the shorter arm. The liquid, in the present case, performs the office of the lever, and the inner surface of the vessel containing it performs the office of the fulcrum. Nor is there, in the fact that 1000 lbs. on the piston P′ are raised by the descending force of 1 lb. on the piston P, anything which might not be naturally expected. If the piston P descend one inch, a quantity of water which occupies one inch of the cylinder O will be expelled from it, and as the vessel A B C D is filled in every part, the piston P′ must be forced upwards until space is obtained for the water which has been expelled from the cylinder O. But as the sectional area of the cylinder O′ is 1000 times greater than that of the cylinder O, the height through which the piston P′ must be raised to give this space will be 1000 times less than that through which the piston P has descended; therefore, while the weight of 1 lb. on P has been moved through one inch, the weight of 1000 lbs. on P′ will be raised through only the $\frac{1}{1000}$th part of an inch. If this process were re-

peated a thousand times, the weight of 1000 lbs. on P′ would be raised through one inch; but in accomplishing this, the weight of 1 lb. acting on P would be moved successively through 1000 inches. The mechanical action, therefore, of the power in this case is expressed by the force of 1 lb. acting successively through 1000 inches, while the mechanical effect produced upon the resistance is expressed by 1000 lbs. raised through one inch.

Now, it is evident that in this there is nothing really paradoxical or difficult.

If the power could act directly on the 1000 lbs. which rest upon the piston P′, and could separately raise them pound by pound one inch, it would accomplish the same mechanical effect without the instrumentality of the hydrostatic apparatus here described.

4. **The hydraulic press.**—An engine, founded on this principle, is well known as the hydraulic press. The idea of such an engine appears to have been first suggested by Pascal, but the practical difficulties attending its construction rendered the theoretical suggestion of that eminent philosopher barren, until the English engineer, Bramah, contrived means to surmount the difficulties which attended its practical construction. This was accomplished about the year 1796, since which time the engines which we are now about to describe have been extensively applied in the industrial arts, the name of the engineer who rendered it practicable being conferred on it, in preference to that of the philosopher who suggested it.

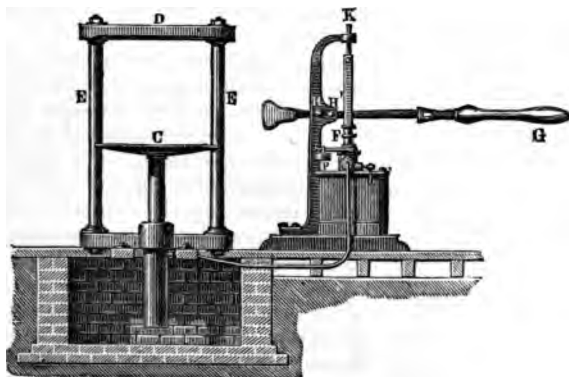


Fig. 3.

The hydraulic press, in one of its most usual forms, is represented in *fig.* 3., and a section of its working parts is shown in *fig.* 4.

A solid plunger I, moving through a water-tight collar, descends into a small cylinder, at the bottom of which there is a valve M, which opens upwards, and communicates with a pipe which descends into a cistern of water.

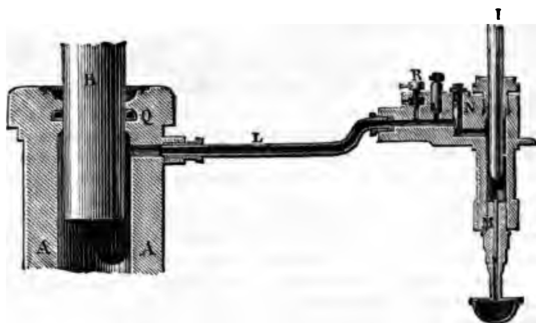


Fig. 4.

In the side of this small cylinder there is a narrow passage, which leads to a tube L, inserted in the side of a large cylinder A A, in which a ram B is inserted, passing through a water-tight collar Q. On the top of this ram, a strong iron plate C is mounted, which is surrounded by a frame E D of adequate strength.

Now, let us suppose the plunger I drawn to the top of the small cylinder; and the barrel of that cylinder, the communicating passages, and tube L, and also the barrel of the large cylinder A A, to be filled with water. If the plunger I be forced downwards, the pressure it produces will be transmitted by the water through the intermediate passages to the ram B, and, according to what has been explained, each square inch in the section of this ram, will receive an upward pressure equal to the downward pressure imparted to each square inch of the section of the plunger I. Thus, if the diameter of the section of B be twenty times that of I, the upward pressure received by B will be 400 times the downward pressure imparted to I.

This pressure acting upon B will be transmitted to the plate C, and any object placed upon that plate, so as to be enclosed between it and the top D of the frame, will be compressed.

When the plunger I has been driven to the bottom of the small barrel, it will displace as much water as is equal to the volume of the part which has descended into the barrel; and this water, being driven through the intermediate passages, will have passed into the large cylinder A A, and, since that cylinder was already full, the ram B will have been compelled to rise through a height sufficient to afford room for the water thus driven into the cylinder A A. The height to which the ram B must rise consistently with this condition, will evidently be less than that through which the plunger I has descended in the same proportion in which the sectional area of the plunger I is less than that of the ram B. Thus, if, as above supposed, the section of the ram B is 400 times that of the plunger I, the ram will rise through the 1-400th part of an inch for every inch through which the plunger I descends.

The plunger I being driven to the bottom of the barrel, the operation

cannot be repeated without drawing it up again to the top; but if that be done, the reaction of the ram B would drive the water back through the intermediate passages into the small barrel, and the ram B would accordingly fall through exactly the same height as that through which it had just been raised by the descent of the plunger I, so that the work which had been accomplished would be again undone.

This is prevented by a combination of two valves, one of which, placed at N, is opened by pressure directed from the small pump barrel towards the great cylinder A A. When the plunger I is driven downwards, the pressure imparted to the water towards A A, opens this valve. and the water is driven in; but when the plunger is raised, the reaction of the ram B, transmitted to the valve N, keeps it firmly closed so that the water cannot return, and consequently the ram B is sustained at the height to which it had been raised.

But the elevation of the plunger I, relieving the water remaining in the bottom of the small barrel from all incumbent pressure, the water in the cistern, into which the barrel descends, forces open the valve M so that the water rushes in and fills the barrel of the pump. When the plunger I is again forced down, the pressure transmitted by the water closes the valve M, so as to prevent the return of the water to the cistern, and opens the valve N, so as to allow it to pass into the great cylinder A A, and to drive the ram B upwards as before.

If proper means, therefore, be provided by which the ram I can be worked alternately downwards and upwards, the ram B can be gradually raised with a force just so much greater, but with a motion just so much slower, than those with which the plunger descends, as the sectional area of the ram is greater than that of the plunger.

The mechanism by which the plunger I is usually worked, is shown in *fig.* 3. The rod of the plunger at the top is connected with an iron link, which is attached to the arm of a lever G, working on a pin at H. The hand of the operator, being applied at G, is enabled to transmit to the rod of the plunger a force which is increased in intensity in the same proportion as the arm G H is greater than the distance of the link F K from the pin H.

If it should be found that the resistance opposed to the ram B is greater than the strength of the operator, applied at G, can overcome, he can increase the efficiency of his own power by transferring the pin, on which the lever plays, from H to H′. Thus, if the distance of H′ from the link F K be half that of H, the efficiency of the power will be doubled.

A valve, closed by a screw at R, communicates with a pipe which leads to the cistern in which the pump is immersed. This valve is closed while the press is in operation; but when it is desired to relieve the ram B from the pressure, to cause the plate C to descend, and to discharge the water from the great cylinder A A, the screw R is turned, so as to open the valve, when the reaction of B will drive back the water through L and through the pipe by which R leads into the cistern.

The principal difficulty in the practical construction of this machine, and that which so long retarded its realisation, is to render the ram B perfectly water-tight in the ring or collar through which it moves in the top of the great cylinder A A, subject to the enormous pressure which acts upon it. It was by the successful

accomplishment of this that Bramah first succeeded in solving the problem of the hydraulic press.

A piece of strong leather, well softened by being saturated with liquid, is formed into a large disc, in the centre of which a hole is cut. The leather is then doubled down at the edges, so as to form a ring which is concave downwards, one half of which is represented cut off in *fig*. 5. This ring is made exactly to fit the plunger, and it surrounds it as a collar, as shown in *fig*. 4., so that the water, when pressed upwards, entering the concave part, presses the lips of the leather with all its force against the ram on one side, and against the surface of the cylinder on the other, so as to render the contact perfectly water-tight both within and without; and the more intense the pressure, the more effectually water-tight will the contact be rendered.



Fig. 5.

Where pressures so intense are produced, a liability of bursting or fracturing some parts of the machine might arise. This is prevented by a safety-valve shown at F in *fig*. 3., and on a larger scale in *fig*. 6. A pipe communicating with the interior of the great cylinder A A, is stopped by a valve which opens outwards, and which is kept closed by a weight P, attached to the longer arm of the lever. This weight is so regulated that when the pressure transmitted to the ram has obtained a dangerous limit, the valve is opened, and the machine relieved.

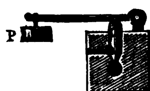


Fig. 6.

The hydraulic press is of extensive use in the industrial arts. In paper factories it is used for compressing the paper in quires. In printing houses for compressing the printed sheets, so as to efface the relief produced by the types. In book-binding establishments to give compactness to the volume before putting on the covers. In establishments for the fabrication of cloth, candles, vermicelli, and numerous other articles to which the proper form or condition is imparted by severe pressure, it is also used. It is found to be a most convenient agent for testing the strength of materials, as, for example, in the case of chain cables provided for the navy.

5. **Press by which the Britannia tubular bridge was erected.** — This was the most stupendous specimen of the machine, whose principle has been explained above, that has ever been constructed.

The weight and bulk of this cyclopean engine were in accordance with its vast mechanical power. The great cylinder was 9 feet long, 22 inches internal diameter, 10 inches thick, and weighed 15 tons! It was a mass of cast iron. Allowing for waste, and for the head or "git," 22 tons of fluid incandescent iron were

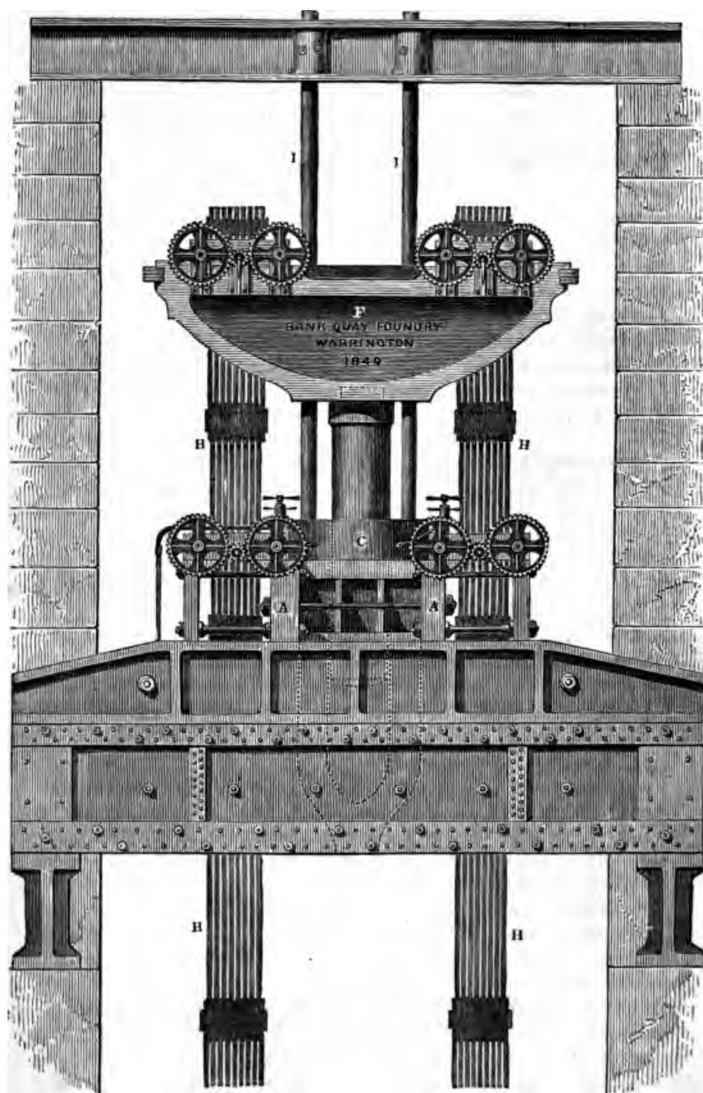
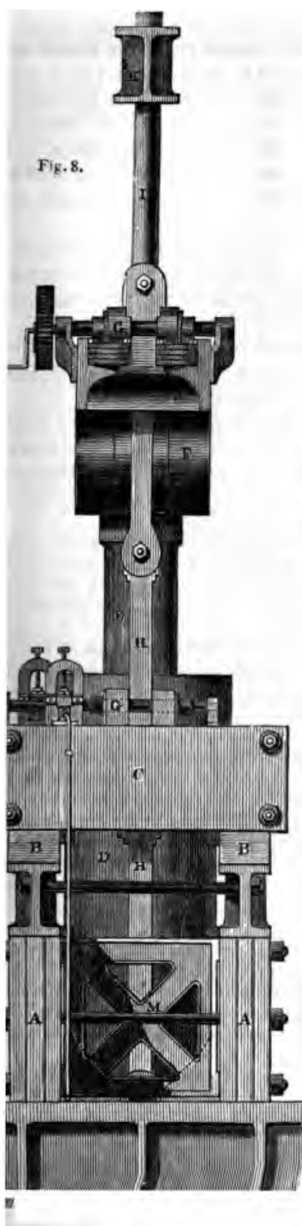
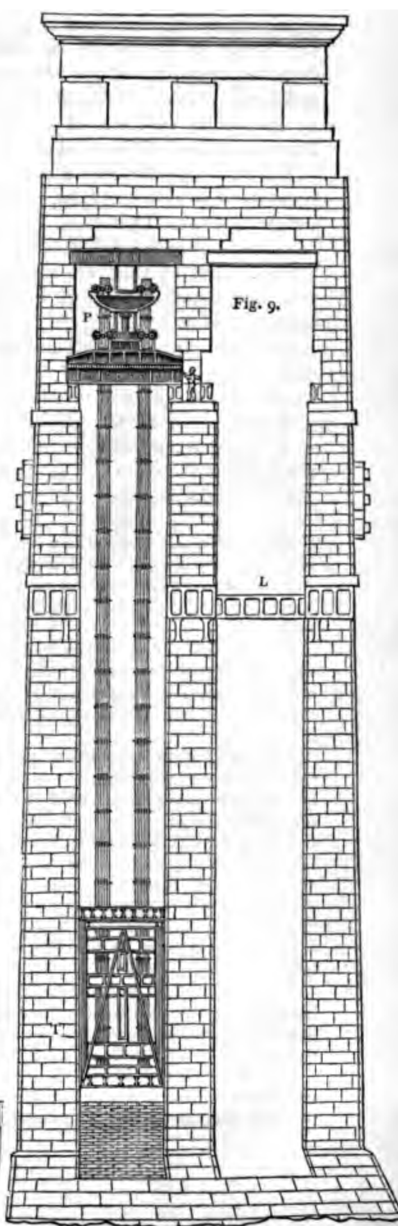


Fig. 7.


Fig. 8.
I
G
F
H
G
C
B
D
H
B
A
M
A


Fig. 9.
P
L

required for this enormous casting. After being left for seventy-two hours in the mould in which it was cast, the mould was detached from it. *It was still red hot!* It was then left to cool, and it was *ten days* before it was sufficiently cool to be approached by operatives well inured to heat for the purpose of detaching from it the part of the sand of the mould which still adhered to it.

The ram, the immediate object that receives and transmits the pressure, was also cast iron, measuring 20 inches diameter, and weighing 3 tons, 13 cwt.

When the weight and bulk of these working parts, and the vast force exerted by them are considered, it will be easily understood that corresponding strength must be provided in the framing and moulding of it.

The form, arrangement, and operation of this vast piece of hydraulic machinery will be more clearly understood by referring from our description of its several parts, to the figures.

A front view of the machine is represented in *fig.* 7., a side view in *fig.* 8., and the manner in which it was applied to elevate the tubes is shown in *fig.* 9. The same letters indicate the same parts in these diagrams.

The cylinder D is enclosed in a cast iron jacket C, bound round by wrought iron slabs, which being placed around it when red hot, were allowed to cool, and in cooling contracted so as to grasp the casting with irresistible force. The weight of this compound jacket of cast and wrought iron is eight tons.

The cylinder and ram thus enclosed in the jacket rest upon horizontal beams B, of cast iron, each of which weighs five tons. These beams themselves rest upon compound girders A, of curious construction, which form the basis and bear the entire incumbent weight of this immense piece of machinery.

These girders are composed of plates of wrought iron 5-16ths of an inch thick, alternated with boards of American elm $2\frac{1}{8}$th inches thick, the timber and the iron being united after the fashion of a *sandwich*, and the entire girder being composed of six plates of iron alternated with six interposed boards of elm. This compound beam of wood and iron, the plates and boards being placed with their planes vertical, their edges being presented upwards and downwards, is secured at top and bottom by twelve wrought iron bars extending the whole length of the beam.

The weight of each of these *sandwiches* is 12 tons!

But let us see the means whereby the ram was made to elevate the bridge.

To the top of the ram was attached a cross-head F, of cast iron. The ram, being, as we have stated, a cylindrical rod 20 inches in diameter, is let into a hole of corresponding size made in this cross-head, on which it is securely fastened. The weight of this cross-head is 13 tons.

To prevent the ram from suffering any lateral strain during its action, the cross-head is made to work on vertical guide rods I, of wrought iron, each 6 inches in diameter, which are fixed in sockets K, on the top of the press. To

the cross-head were attached the chains H, which descended to the level of the water and embraced the tube to be raised.

The greatest weight lifted by the press was 1144 tons, but it was capable of raising 2000 tons. The quantity of water injected into the great cylinder, in order to raise the ram 6 feet, was 81½ gallons. When a lift of 6 feet was effected, the lifting chains

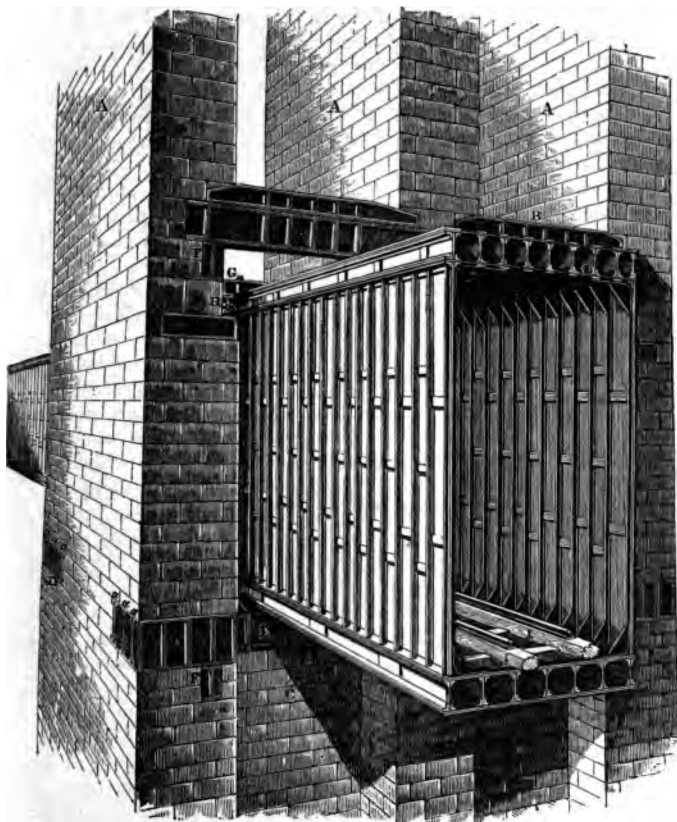


Fig. 10.

were seized by a set of clamps under the lowest point to which the cross-head descended, and while they were thus held suspended, the water was discharged from the great cylinder, and the ram,

with its cross-head, made to descend. Meanwhile, the lengths of the chains above the clamps were removed, and the chains thus shortened attached to the cross-heads by other clamps connected with the cross-head, and all was prepared for another lift.

In the practical operation of the machine, each lift of 6 feet occupied from thirty to forty-five minutes.

The manner in which the tubes were elevated is indicated in *fig.* 9. The square section of the tube is represented at T, filling a space between two piers of masonry. The chains attached to it are continued upwards to the press P. When, by the operation of the press, the tube was lifted through a height of 6 feet, the vacant space under it was built up. The same process was repeated after each lift, until at length the tube was raised to the intended level L, of the roadway.

To facilitate still more the conception of this stupendous mechanical operation, we give, in *fig.* 10., a perspective view of a portion of the tubes, resting upon the centre tower in the middle of the Strait.

6. The apparatus called the *hydrostatic bellows*, represented in *fig.* 11., acts upon the same principle.

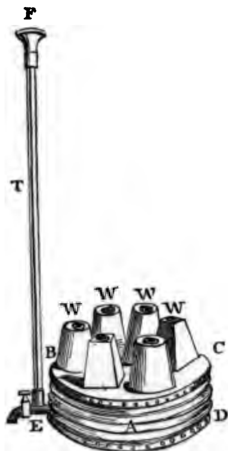


Fig. 11.

Two boards B C and D E are united by a flexible cloth, like a common bellows. The vertical tube T communicates with the interior, through the short pipe E, at right angles to it, which is also supplied with a stop-cock, by which the water contained in the bellows may be discharged. The apparatus being empty, let it be loaded with the weights W, and let water be then poured in at the funnel E; as the bellows fills, the weights will be raised, and the weight of a small column of water in the vertical pipe T will be capable of supporting a weight upon the board B C, greater than the weight of the water in the pipe, in the same proportion as the area of the board B C is greater than the sectional area of the bore of the pipe. Thus, if we suppose the area of the bore of the pipe to be a quarter of an inch, and the area of the board to be a square foot, then the proportion of the pipe to the area of the board will be that of 576 to 1; consequently, the weight capable of being supported by the board will be 576 times the weight of the water contained in the pipe.

7. This power of liquids to transmit pressure to a distance was

proposed as a means of telegraphic communication before the invention of the electric telegraph.

It was proposed that small water pipes should be buried along the lines of road, and that a pressure produced upon the column of water at any one place being transmitted to any other place, however distant, should be used as a signal. Thus, if a tube filled with water extended from London to Edinburgh, a pressure exerted on the liquid at the end of the tube at London would cause a corresponding pressure or motion at the end of the column at Edinburgh, no matter what might be the course of the tube between the two places, whether straight, curved, or angular, and whether the pipes proceeded downwards, obliquely, or horizontally, or whether they were carried through the walls of a building, or the course of a river, or under, over, or around any obstruction or impediment whatsoever.

The same property of transmitting pressure has been proposed to be applied to several purposes, where it is required to produce a pressure on some internal part which cannot be approached except by a flexible tube, through which an instrument cannot safely or conveniently be inserted.

CHAP. II.

THE PRESSURE OF LIQUIDS DUE TO THEIR WEIGHT.

8. THE property by which liquids transmit pressure freely in every direction being understood, the manner in which this property modifies the effects of their own weight, and distinguishes them from those which attend the weights of solid bodies, remains to be explained.

If a solid body be placed in a vessel having a horizontal bottom and upright sides, and so corresponding in shape to the body that the latter shall exactly fill it as a plug would fill a tube, the effect of the weight of such a body, placed in such a vessel, would be to press with its whole force upon the horizontal bottom, no pressure whatever being exerted on the sides. If in such a case the sides were detached from the vessel, the body contained in it would remain undisturbed, pressing upon the bottom as before. But if we suppose the body thus contained in the vessel to be liquefied, we shall then be unable to remove the sides without totally disarranging the state of the body, since, the moment the body becomes

liquid, the sides will have to resist the tendency of its component particles to fall asunder, which tendency was before resisted by that mutual cohesion which constitutes the character of solid bodies.

The change from solid to liquid would in this case make no change in the pressure produced upon the horizontal base of the vessel; but the pressure on the sides will depend on conditions determined by the depth of the particles of fluid, whic we shall now explain.

Let A B C D (*fig.* 12.) be such a vessel as is above described, B C being the horizontal bottom, and A B and D C vertical sides. If it be filled with a solid body of its own form, the upper surface of which, E F, is level and parallel to the bottom B C, this body will press upon the bottom B C with the full amount of its weight, and no pressure whatever will be exerted on the perpendicular sides A B and D C. But if such body be liquefied, a pressure will immediately take place on all the sides, the pressure on the bottom remaining the same as before.

Fig. 12.

Let O be a part of a level stratum of the liquid, which we shall suppose to have the magnitude of a square inch, and to be placed anywhere within the dimensions of the liquid. It is evident that the surface O will sustain directly the pressure of the vertical column of liquid O P, which is immediately above it, extending from the surface of the liquid downwards to O. This pressure will be equivalent to the weight of the column; that is to say, of as many cubic inches of the liquid as there are inches in the depth of the stratum O below the level. It appears, therefore, evident, that every square inch of any stratum of the liquid must sustain a downward pressure equal to the weight of a column of the liquid whose base is a square inch, and whose height is equal to the depth of the proposed stratum.

But since this downward pressure is transmitted equally in every direction, it is clear that it will be transmitted to the sides of the vessel, and will act upon them laterally with the same force as that with which it acts downwards; consequently it follows, that a square inch of the vessel at O′, in the same level stratum with O, will sustain a pressure perpendicular to the surface of the same amount.

9. **Pressure proportional to depth.** — It follows, therefore, in general, that *each square inch of the surface of a vessel containing a liquid is pressed by a force perpendicular to such surface, equal to the weight of a column of the liquid whose base is a square inch, and*

whose height is equal to the depth of the point of surface in question below the level of the fluid.

In *fig.* 12. the sides of the vessel are represented to be perpendicular, but the same reasoning will be applicable, whatever be their position. Thus, if they diverge from the bottom, as in *fig.* 13., the pressure produced upon a square inch of the surface of

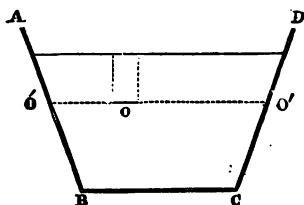


Fig. 13.

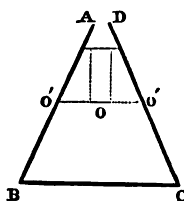


Fig. 14.

the side at o' will, for the same reason, be equal to the weight of a column of the liquid whose height is equal to the depth of the point o, and whose base is a square inch.

Again, if the sides converge, as in *fig.* 14., the same principle will obtain.

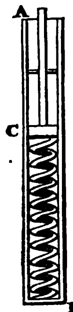


Fig. 15.

10. There are several expedients by which this pressure of liquids proportional to their depth can be verified experimentally.

Let A B (*fig.* 15.) be a strong metal cylinder, open at A and closed at B, in which a piston C moves water-tight, and rests upon a spiral spring extending to the bottom B, so that any force tending to press the piston downwards is resisted by the elasticity of the spring. If such an instrument be plunged to any depth in a liquid, the piston will be pressed inwards with a force corresponding to the pressure of the liquid.

Now it is found by experiments made with this instrument, that the pressure which urges the piston from C towards B is always equal to the weight of a column of the liquid in which it is immersed, whose base is equal to the magnitude of the piston C, and whose height is equal to the depth of the piston below the surface of the liquid. It is further proved, that this pressure is equally exerted in every direction, because the piston will act against the spring with the same force, in whatever position the instrument may be placed. If it be placed vertically with the open end A upwards, it will indicate the downward pressure of the liquid; if it be placed vertically with the end B upwards, it will indicate the upward pressure of the liquid; if it be placed

with the length A B horizontal, it will indicate the lateral pressure; and in all intermediate positions it will indicate the pressure in every other possible direction.

In all these cases, the piston will compress the spring to the same point, whatever direction be given to the instrument, provided only the piston C be kept at the same depth.

11. From what has been just established, it follows that the pressure upon any part which is horizontal of the surface of a vessel containing a liquid will be uniform, and will be equal to the weight of a column of the liquid whose base is equal to the lower surface, and whose height is equal to the depth of such surface below the level of the liquid; and in this case it must be observed that it is not necessary that a column of the liquid should be actually above the surface in question. This consequence leads to another form under which the hydrostatic paradox presents itself.

12. **Another form of the hydrostatic paradox.**—Let A B C D (*fig.* 16.) be a closed vessel, with a small hole in the top, in which a narrow tube T O is screwed, water-tight. Let the vessel A B C D and the tube T O be filled with water. According to what has been established, the pressure on the bottom C D will be equal to the weight of a column of water whose base would be equal to the area of the bottom C D, and whose height would be T M; that is, it would be equal to the quantity of water which would fill a vessel whose base is C D, having perpendicular sides D E and C F. This will be true, however shallow the vessel A B C D, and however narrow the tube T O, may be; and hence an indefinitely small quantity of water may be made to produce a pressure on the bottom of the vessel which contains it, equal to the weight of any quantity of water, however great. As the pressure depends only on the depth of D C below the level of the water in the tube T O, it is not necessary that the tube T O should be straight; it may be bent or deflected in any direction or form whatever; but whatever be its shape, the depth of the fluid which determines the pressure is to be estimated by the perpendicular distance of its upper surface in the tube from the bottom of the vessel.

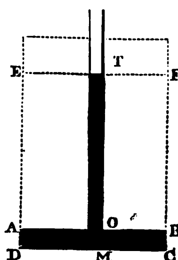


Fig. 16.

13. **Experimental illustration.**—The principle here explained may be experimentally verified by an apparatus represented in *fig.* 17., consisting of a horizontal tube, with two short tubes connected with it at its extremities at right angles. To these vertical pieces, vessels of glass of different forms (*figs.* 18. 19.)

can be screwed. Now, let it be supposed that mercury is poured into the horizontal tube until that tube and part of the vertical tubes are filled, the mercury will then stand at the same level in

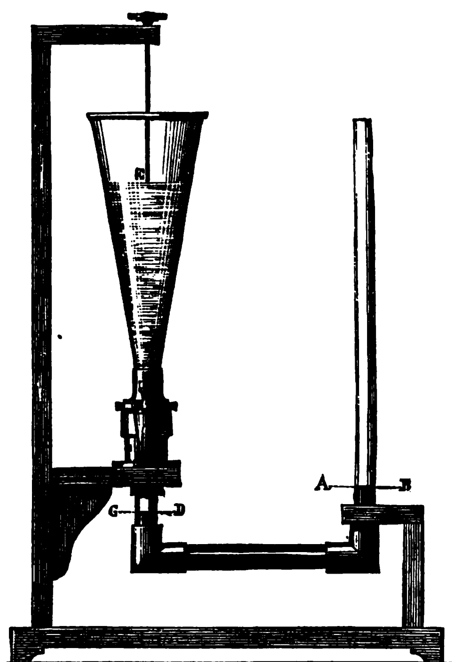


Fig. 17.



Fig. 18.



Fig. 19.

the two vertical tubes. Let a straight tube of uniform bore be screwed upon one, and a funnel-shaped vessel E, on the other.

Let water be poured into the vessel E, until its level rises to the point of a vertical rod shown in the figure, which descends to a certain depth in the vessel; the pressure of the water acting upon the mercury in one vertical tube will cause the mercury in the other to rise, until the difference of the levels A B and C D represents the height of the column of mercury, whose weight is equal to the pressure of the water upon C D.

Now suppose the funnel-shaped vessel E to be removed, and to be replaced successively by the tubular vessels represented in *figs.* 18. and 19., the former having a greater and the latter a less diameter than the tube C D. Let water be poured into these suc-

cessively until its surface touches the point of the vertical rod: it will be found in each case, that the difference of the levels A B and C D, of the mercury in the two vertical tubes, will be the same, proving that the pressure on C D depends only on the depth of the water, and not at all on the form of the vessel containing it.

The same result would be obtained if a vessel in the shape of an inverted funnel, the wider end downwards, were screwed upon the tube C D.

14. **Lateral pressure.** — If any part of the surface of a vessel containing a liquid be not horizontal, the pressure against its different parts will vary according to their depth. Let A B C D (*fig.* 20.) be a vessel with a flat bottom and perpendicular sides, and let it be supposed to be filled with water. The depth of the side A B, being divided into ten equal parts, let us suppose that the pressure produced against the first division of the side between 0 and 1 is one pound; then the pressure produced against the division between 1 and 2 will be two pounds, the pressure against the division between 2 and 3 will be three pounds, and so on; so that, in fine, the pressure produced against the last division between 9 and 10 will be ten pounds.

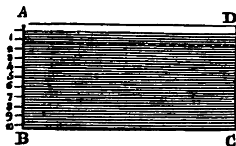
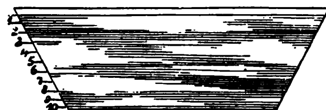


Fig. 20.

Since, therefore, the intensity of the pressure from A to B increases uniformly with the depth, the average pressure will be found at the fifth division, being the middle point of the depth, and the total pressure upon the side will be the same as if it sustained such average pressure upon the fifth division, distributed uniformly over the whole surface. Hence it follows that the total pressure upon the side of such a vessel will be equal to the weight of a column of the liquid whose base is equal to the area of such side, and whose height is equal to one half the depth of the liquid in the vessel, or, in other words, to the depth of the middle point of the side below the surface.

We have here supposed the side of the vessel to be vertical; but


Fig. 21.

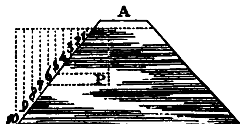


Fig. 22.

the same conclusion will follow if it be inclined either outwards, as in *fig.* 21., or inwards, as in *fig.* 22.

In all cases, therefore, where the surfaces which contain a liquid are either vertical, or inclined to the vertical line, the total pressure which they sustain can be found by multiplying the number of square feet in the area of such surfaces by the number of feet in the depth of its middle point, or more generally by the number of feet in the perpendicular distance of its point of average depth below the surface.

15. It follows, therefore, that the actual pressure produced upon the bottom and sides of a vessel which contains a liquid is always much greater than the weight of the liquid. If, for example, the vessel have a cubical form, the pressure on the bottom will be equal to the weight of the liquid, and the pressure on each of the four sides will be equal to one half the weight of the liquid; consequently, the total pressure on the bottom and sides will be exactly three times the weight of the liquid contained in the vessel.

In tall narrow vessels containing liquids, the pressure against the sides far exceeds the weight of the liquid: tall casks, cisterns, and tubes, which have a vertical direction, require to have a lateral strength very far exceeding that which would be necessary merely to support the liquids they contain.

16. **Pressure on dam or embankment.** — The increase of pressure proportional with the depth suggests the expediency of observing a corresponding variation in the strength of the several parts of embankments, dams, flood-gates, and other resistances opposed to the course of water.

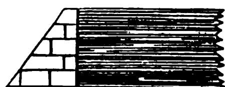


Fig. 23.

The pressure near the surface is inconsiderable, and therefore a small degree of strength is sufficient in the resisting surface; but as the depth increases, the pressure increases in the same proportion. If, therefore, as in the case of dams and embankments, the strength depends upon the thickness, the thickness must gradually increase from the top to the bottom, in proportion to the depth; so that while the interior surface presented to the liquid is perpendicular, the exterior surface will gradually slope, giving increased thickness to the wall or dam, as represented in *fig.* 23.

The pressure produced by a liquid on the horizontal bottom of the vessel containing it depends exclusively on the magnitude of such bottom and the depth of the liquid, and is altogether independent of the shape, magnitude, or position of the sides, and therefore of the quantity of liquid contained in the vessel.

17. **Experimental verification.** — It has been shown that in a vessel with perpendicular sides and horizontal bottom, such as that represented in *fig.* 20., the pressure on the bottom is equal to the total weight of the liquid contained in the vessel; but if the

shape of the vessel were that represented in *fig.* 21., the pressure on the bottom would still remain the same, although the quantity of liquid would be considerably greater; and if the vessel were shaped as in *fig.* 22., the bottom being still the same, the pressure on the bottom would remain the same, although the quantity of liquid in the vessel would be considerably less. These results may be verified experimentally in various ways.

Thus, if three vessels be provided, the first with perpendicular, the second with diverging, and the third with converging sides, each having a movable bottom fitting it water-tight, let the bottoms be pressed against each vessel with equal forces, which may be done by a lever, one arm of which is pressed upwards against the bottom by a weight suspended from the other arm. If water be then poured into the vessels severally until such a quantity has been introduced that its pressure on the bottom shall overcome the resistance of the lever, it will be found that the depth of the water in each case necessary to accomplish this is the same.

Another method of illustrating experimentally the same principle, is as follows:—Let the movable bottom be pressed against each vessel by a string attached to it on the inside, and carried up through the vessel, and then let the vessels be plunged in a cistern

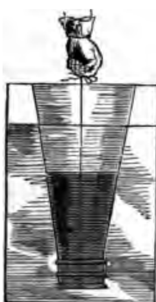


Fig. 24.



Fig. 25.

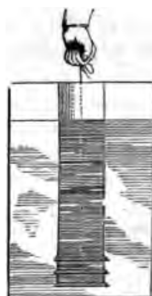


Fig. 26.

of water, as represented in *figs.* 24, 25, and 26., until they attain such a depth that the upward pressure of the water against the bottom will be sufficient to keep it attached to the vessel.

If the vessel be immersed to the same depth, the upward pressure thus acting upon the bottoms will be the same. Let water be poured into each of the three vessels. It is evident that when such a quantity shall have been introduced as shall produce a downward pressure upon the bottom equal to the upward pressure, the bottom will no longer adhere, and it will fall. Now it is

found by experiments conducted in this manner, that it requires the same depth of water in each of the three vessels to accomplish this.

18. In the preceding examples, the surfaces confining the liquid have been considered to be flat. The surfaces, however, of vessels and reservoirs are subject to a variety of forms; and it is necessary in practical science to be in possession of rules which are applicable generally to all such surfaces.

The various parts of a surface containing a liquid will, according to the principles established, be subject to pressures depending only upon the depths below the surface of the liquid in the vessel, all parts of the same depth being subject to the same pressure. If we imagine the entire surface of a reservoir below the level of the water to be divided into square inches, each square inch will sustain a pressure equal to the weight of a column of water whose base is a square inch, and whose height is equal to the depth of the square inch of the surface in question.

The total pressure, therefore, sustained by the surface of the reservoir, may be ascertained if the average depth of the surface below the level of the water could be determined, as in this case the total pressure exerted by the liquid on the surface of the vessel or reservoir would be equal to the weight of a column of the liquid, whose base would be equal in area to the entire surface of the vessel or reservoir, and whose height would be equal to the average depth of this surface.

19. **Point of average depth.**—Mathematical science supplies a method by which this point can be in all cases calculated.

If we suppose a thin sheet of any uniform substance, such as metal, to be spread over the surface of the reservoir, and in close contact with it, just as the inner surfaces of some vessels are lined with tin-foil, then the point of average depth will be identical with the centre of gravity of such a lining. The methods, therefore, by which the centre of gravity is determined, supply the means of ascertaining the points of average depth in all vessels and reservoirs; and these points being ascertained, the total pressure upon them can be computed.

20. **Examples.**—Excepting in the case of certain surfaces of regular form, the determination of the centre of gravity is a problem which cannot be solved without the application of mathematical principles of considerable difficulty. The theorem, however, just stated, may be illustrated by examples sufficiently simple to be generally understood.

Let a hollow sphere be filled with a liquid through a small hole on the top. The centre of gravity of the surface of the sphere is evidently its centre, and therefore the depth of this point below the

height at which the level of the liquid stands is one half the diameter of the sphere. The total pressure will therefore be found by multiplying the number of inches in half the diameter of the sphere by the number of square inches in its surface. By the principles of geometry, it is proved that the solid contents of a sphere are determined by multiplying the number of inches in half the diameter by a third part of the number of square inches in the surface. Hence it appears that the pressure produced upon the surface of the sphere by the liquid it contains, is three times the weight of its contents.

If a solid be immersed in a liquid, the pressure which its surface suffers from the surrounding liquid is determined by the same principles as those which determined the pressure on the surface of the vessel containing the liquid. Thus, if a sphere be plunged in a liquid, the total pressure upon its surface is found by multiplying the number of inches in the depth of its centre below the surface of the liquid by the number of square inches in its surface.

The two hydrostatical principles which have been established in the preceding chapter and the present one, that liquids transmit pressure equally in all directions, and that the pressure they produce by their own weight is proportional to the depth, serve to explain many familiar and remarkable facts.

21. **Pressures of different liquids different.** — But to render them applicable to such exposition, it is not sufficient to know the laws determining the transmission and the variation of the pressure. It is necessary also to know the actual amount of this pressure for each particular liquid. Thus, for example, if two equal and similar vessels be filled to the same depth, the one with water and the other with quicksilver, it is evident that the pressure produced upon any part of the surface of the one will be greater than the pressure produced upon the corresponding part of the surface of the other, in exactly the same proportion as quicksilver is heavier than water.

To be enabled, therefore, to declare the actual intensity of the pressure produced in each case, it would be necessary to know the actual pressure which would be produced upon a surface of given magnitude by a column of water of given height; and further, to know the proportion which the weight of other liquids under inquiry would bear bulk for bulk to the weight of water.

22. **Actual pressure of water.** — We shall hereafter explain how the proportional weight of other liquids is ascertained and recorded. For the present we shall limit our observations to the most universal of all liquids, water.

It is ascertained that the weight of a cubic inch of water of the

common temperature of 62° Fahr. is a portion of a pound expressed by the decimal 0·036065. The pressure, therefore, of a column of water one foot high, having a square inch for its base, will be found by multiplying this by 12, and consequently will be 0·4328 lb.

The pressure produced upon a square foot by a column one foot high, will be found by multiplying this last number by 144; the number of square inches forming a square foot in which will therefore be 62·3232 lbs.

23. *Table showing the pressure in lbs. per square inch and square foot, produced by water at various depths.*

Depth in Feet.	Pressure per Square Inch.	Pressure per Square Foot.	Depth in Feet.	Pressure per Square Inch.	Pressure per Square Foot.
	lbs.	lbs.		lbs.	lbs.
I.	0·4328	62·3232	VI.	2·5968	373·9392
II.	0·8656	124·6464	VII.	3·0296	436·2624
III.	1·2984	186·9696	VIII.	3·4624	498·5856
IV.	1·7312	249·2928	IX.	3·8952	560·9088
V.	2·1640	311·6160	X.	4·3280	623·2320

By the aid of the above table, the actual pressure of water on each part of the surface of a vessel containing it can always be determined, the depth of such part being given.

Thus, for example, if it be required to know the pressure upon a square foot of the bottom of a vessel where the depth of the water is 25 feet, we find from the above table, that the pressure upon a square foot at the depth of 2 feet is 124·6464 lbs.; and, consequently, the pressure at the depth of 20 feet is 1246·464 lbs.: to this, let the pressure at the depth of 5 feet, as given in the table, be added,

$$\begin{array}{r} 1246{\cdot}464 \\ \underline{311{\cdot}616} \\ 1558{\cdot}080 \text{ lbs.} \end{array}$$

which is therefore the required pressure.

24. If the liquid contained in the vessel be not water, but any other whose relative weight compared with water is known, the calculation is made first for water, and the result being multiplied by the number expressing the proportion of the weight of the given liquid to that of water, the result will be the required pressure. The manner of determining this relative weight will be given hereafter.

25. **Pressure at great depths.**—If an empty bottle tightly corked be sunk in the sea, the pressure of the surrounding water, when the depth is sufficient, will either break the bottle or

force the cork into it. If the bottle have flat sides, it will be broken; if it be round, its form being stronger, the cork will be forced in.

If a piece of wood which floats on water be sunk to a great depth in the sea, and held there for a certain time, the great pressure of the surrounding liquid will force the water into the pores, the effect of which will be to increase its weight so that it will no longer be capable of floating or rising to the surface.

Divers plunge with impunity to certain depths, but there is a limit below which they cannot live under the intense pressure. It is probable, also, that there is a limit of depth below which each species of fish cannot live.

26. The preceding principles will enable us to explain the method of constructing partitions in the workings of mines, having for their object to exclude from certain galleries the water

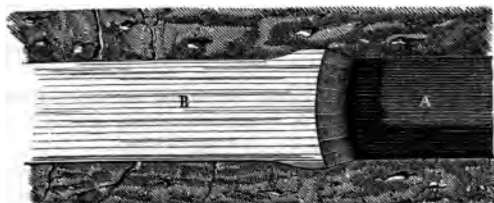


Fig. 27.

which inundates adjacent ones. Thus, let B (*fig.* 27.) represent the section of a gallery which is inundated by water percolating through the fissures and interstices of the superjacent strata. This water is excluded from the neighbouring gallery A, by an arched wall built between them, the convexity of which is presented against the water. It might be supposed in this case that considering the very limited dimensions, even of the largest galleries, the hydrostatic pressure exerted against the partition of masonry could not be so great as to require the strength of an arch to resist it. But it must be considered that the pressure exerted against such a partition, is not merely that due to the height of the gallery, but to the height of the columns of water in the superior fissures by which the gallery is inundated, a height which is often very considerable. Let us suppose, for example, that the level of the water in the fissures is 300 feet; the pressure, in that case, against the partition, will be that which would be produced by the entire weight of a column of water whose base is the surface of the partition, and whose height is 300 feet; and since this pressure is 62·32 lbs. on every square foot of surface for

every foot of height in the column, the pressure per square foot produced by a column 300 feet high, would be about 18700 lbs., or little less than 9 tons.

In fact, the case here presented is only an example on a large scale of the hydrostatic paradox.

27. **Surfaces of separation of different liquids level.** — If two or more different liquids, which are incapable of mixing one with another, be poured into the same vessel, they will, when they come to rest, arrange themselves in strata one above the other, the surfaces of which will be parallel and horizontal. Thus, for example, if mercury, water, and oil be poured into the same bottle and shaken together, when the bottle is placed at rest on the table, the mercury will settle at the bottom, the water resting above it, and the oil above the water; and the upper surface of the mercury, that of the water, and that of the oil, will be severally horizontal or level.

It is easy to show in general that the surface separating any two such fluids must be level if they are at rest; or, what is the same, that if it be not level, they cannot be at rest.

Let F E (*fig.* 28.) be a surface separating two such fluids: the lower and heavier, water, and the upper and lighter, oil, for example. Now let us suppose a level stratum of the water to be taken at any proposed depth, such as B A; the downward pressure upon B will be the weight of the column B F of water, and that of the column of oil, extending from F to the surface; while the pressure at A will be the weight of the column A E of water, and that of oil, extending from E to the surface. Now, supposing the surface level, it is evident that the downward pressure at B, produced by a greater column of water and a less column of oil, will be greater than the downward pressure at A, produced by a less column of water and a greater column of oil. The points A and B, therefore, which are at the same level, being subject to unequal pressures, cannot be in equilibrium, and in the same way it may be shown that no equilibrium can be maintained so long as the surface of any fluid in the vessel is not level.


Fig. 28.

28. **Bursting rocks.** — If a fissure in a rock communicate with an internal cavity of any considerable magnitude, placed at some depth below the mouth of the fissure, rain percolating through, and filling the fissure above it, might produce a bursting force sufficient to split the rock. The pressure in this case, acting against the inner surface of the cavity, will be proportional to the depth of the cavity below the top of the fissure. It appears from the table, page 23., that for every foot in such difference of level,

there will be a bursting pressure of 0·4328 lbs. for every square inch of the surface of the cavity.

29. **Water pipes for supply of towns.** — In the construction of pipes for the supply of water to towns, it is necessary that those parts which are much below the level of the reservoir from which the water is supplied should have a strength proportionate to such difference of level, since they will sustain a bursting pressure of 4·328 lbs. per square inch for every 10 feet by which the level of the river exceeds in height that of the pipe. A pipe, the diameter of whose bore is 4 inches, has an internal circumference of about one foot, and the internal surface of one foot in length of such a pipe would measure a square foot. If such a pipe were 150 feet below the level of the reservoir, the bursting pressure which it would sustain upon one foot of its length may be calculated as follows, from the table, page 23.:

	lbs.
Pressure at 100 feet deep - - - - -	6232
" 50 " - - - - -	3116
Pressure at 150 " - - - - -	9348

Thus, such a pipe should be constructed of sufficient strength to bear with security nearly five tons bursting pressure on each foot of its length.

CHAP. III

LIQUIDS MAINTAIN THEIR LEVEL.

30. **Surface.** — When a liquid contained in any vessel is in a state of rest, its surface will be horizontal; and if the same liquid be contained in different vessels, which have free communication with each other by tubes, pipes, or otherwise, then the surface of these liquids in the different vessels will be at the same level.

This important property of liquids, which is usually expressed by stating that liquids maintain their level, follows immediately from the two properties which have been established in the preceding chapters.

It may be proved that all parts of the surface of a liquid contained in a vessel must be at the same level when at rest, by showing that if they be not at the same level, the fluid must be in motion, and must continue in motion until they attain the same level.

Let A B C D (*fig.* 29.) be a vessel containing a liquid whose surface is at different levels, as represented at M N, being higher at M than at N.

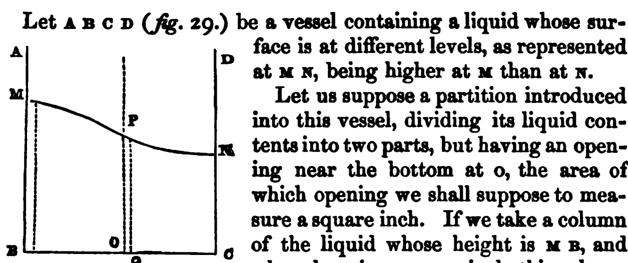


Fig. 29.

Let us suppose a partition introduced into this vessel, dividing its liquid contents into two parts, but having an opening near the bottom at O, the area of which opening we shall suppose to measure a square inch. If we take a column of the liquid whose height is M B, and whose base is a square inch, this column will press at the bottom B with a force equal to its weight, and this pressure will be transmitted equally in every direction throughout the dimensions of the liquid; and consequently it will be transmitted laterally to the orifice O, and through the orifice O it will be transmitted to the liquid on the other side of the partition. It will then likewise press equally in every direction; and if we suppose a column, P Q, having a square inch as its base, this column will be pressed upwards by the same force, but its downward pressure will be equal to the weight of the column P Q. Thus, a horizontal stratum of the liquid, measuring a square inch at O, will be pressed downwards by the weight of the column P Q, and upwards by the weight of the column M B. But the latter being greater than the former, the upward pressure will exceed the downward, and the column P Q will be raised.

The same will be true of every pair of vertical columns into which the liquid on either side of the partition may be resolved; and thus it follows that under such circumstances the liquid will flow from the side M B towards the side N C, the level of the former falling, and that of the latter rising.

But if the column P Q were equal to M B′ (*fig.* 30.), then the downward pressure would be equal to the upward pressure, and no motion would take place; and if the same were true of every pair of columns into which the liquid on either side of the partition could be resolved, then no motion would ensue; that is to say, if the surface, instead of being at different levels, as in *fig.* 29., were at the same level, as in *fig.* 30., then, and not otherwise, the fluid would remain at rest.

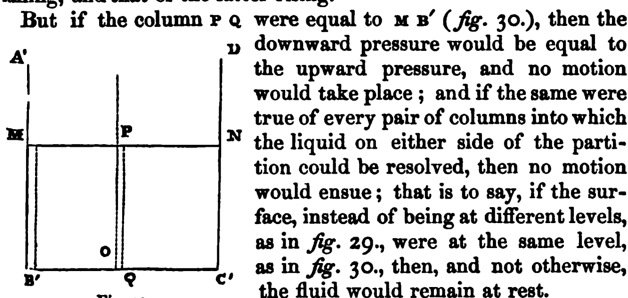


Fig. 30.

We have here imagined a partition to be introduced, dividing the vessel having an orifice near the bottom; but it is evident that the presence or absence of such a

partition cannot affect the movement or the equilibrium of the fluid, since such a partition introduces no force to affect the fluid which did not previously exist.

31. **Examples.** — This property of liquids is so nearly a self-evident consequence of their fundamental property, that it is difficult to demonstrate it. It is nothing more than a manifestation of the tendency of the component parts of a body to fall into the lowest position which the nature of their mutual connection, and the circumstances in which they are placed will admit. Mountains do not sink and press up the interjacent valleys, because the cohesive principle which binds together the component parts of their masses, and those of the crust of the earth upon which they rest, is opposed to the gravity of their parts, and is much more powerful; but if this cohesion were dissolved in the stupendous masses, — for example, if the Alps or the Andes were liquefied, — these ridges would sink from their lofty eminences, and the circumjacent valleys would rise, a momentary interchange of form taking place; and this undulation would continue, until the whole mass would settle down into a uniform level surface. All inequalities, therefore, which we observe on the surface of land, are due to the predominance of the cohesive over the gravitating principle; the former depriving the earth of the power of transmitting equally and in every direction the pressure produced by the latter.

On the other hand, if the sea, when agitated by a storm, were suddenly solidified, the cohesive principle being called into action, the mass of water would lose its power of transmitting pressure, and those inequalities which in the liquid form are fluctuating would become fixed; a wave would become a hill, and an intermediate space a valley.

32. **Maintenance of level.** — The maintenance of level between liquids contained in communicating vessels is established by

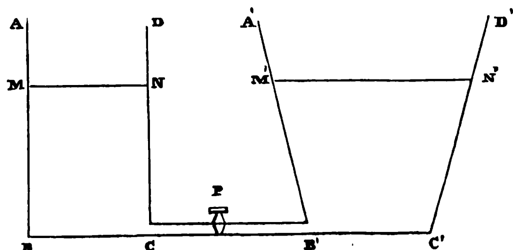


Fig. 31.

reasoning similar to that by which the level surface of a liquid contained in any vessel is proved. Let A B C D (*fig.* 31.), and A′ B′

C′ D′, be two vessels, between which there is a pipe of communication B′ C.

If these two vessels be partially filled with the same liquid, the surface M N of the liquid in the one vessel must be at the same level with the surface M′ N′ of the liquid in the other vessel, provided the liquids are at rest.

Let us suppose a stop-cock at P, in the tube of communication B′ C, this tube being horizontal.

By what has been proved it appears that the pressure exerted by the liquid in A B C D upon the stop-cock will be equal to the weight of a column of the liquid, whose base is equal to the passage of the stop-cock, and whose height is equal to the depth of the stop-cock below the surface M N.

In like manner, the pressure exerted on the other side of the stop-cock by the liquid in the vessel A′ B′ C′ D′, will be equal to the weight of a column of liquid, whose base is equal to the opening of the stop-cock, and whose height is equal to the depth of the stop-cock below the surface M′ N′.

Hence it follows that the stop-cock will be pressed equally in both directions, if the surfaces M N and M′ N′ are at equal heights above it; and consequently in this case, if the stop-cock be opened, there will be no tendency of the liquid to flow in either direction through it.

But if, on the other hand, the surface M N be at a greater height above the stop-cock than the surface M′ N′, then there will be a greater pressure upon the stop-cock on the one side C than on the other B′; and if the stop-cock be opened, the liquid will flow from the vessel A B C D to the vessel A′ B′ C′ D′; and in like manner, if the level M N be lower than the level M′ N′, then the pressure on the side C will be less than the pressure on the side B′, and the liquid will flow in the contrary direction.

It therefore follows, in general, that if the levels of the liquid in the communicating vessels be the same, no motion of the liquid will follow; but if they be not the same, then the liquid will flow from the vessel which has the higher level to the vessel which has the lower level.

33. **Experimental illustration.** — The apparatus represented in *fig.* 32. is adapted to explain experimentally these facts. A, B, C, D, E are glass vessels of different shapes, each terminating at the bottom in a short tube which is inserted into a hollow box. In each of these short tubes is a stop-cock K.

When the cocks are all open, a communication between the five vessels is established through the intervention of the box; but each or all of the vessels can be insulated by closing the cocks.

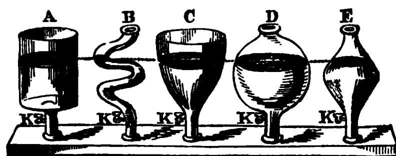
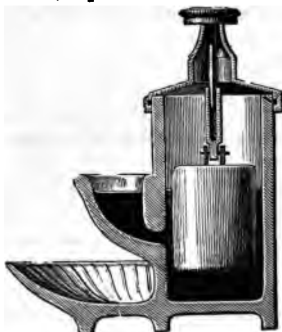


Fig. 32.

Let the stop-cocks be all closed, and let water be poured into the vessels, so as to stand at different levels, the case below being previously filled with water. If all the cocks be now opened, it will be observed that the higher levels will gradually fall, and the lower ones will rise until all become uniform. If the stop-cocks be again closed, and water be poured into some of the vessels, so as to render the levels again unequal, the same equalisation would take place on again opening the stop-cocks.

34. **Fountain ink-bottles.** — When a large surface of liquid is exposed to the air, evaporation takes place, at a rate proportionate to the extent of the surface; this causes ink, when contained in bottles, where any considerable extent of surface is thus exposed, to thicken, the aqueous constituent evaporating and the colouring matter remaining in an undue proportion. Various forms of ink-bottle have been contrived to prevent this, one of which, represented in section in *fig.* 33., depends on the principle in virtue of which liquids maintain their level. A solid plunger is inserted in a hollow cylinder of a little larger diameter, so that it can move freely in it. This plunger hangs from a rod, which can be raised to a certain height by means of a screw, which passes through the cover of the cylinder. When the plunger is raised to the greatest height it admits of, the ink is poured in through the spout, until it rises to the level of the spout in the cylinder. When the ink has been consumed, so that its level falls to the bottom of the spout, the screw in the cover of the cylinder is turned so as to let down the plunger, which displaces a certain quantity of the ink, the level of which, in the cylinder, rises round the plunger. When it has risen nearly to the level of the spout, it will necessarily have risen also to the same level in the spout, and the motion of the screw is suspended. In the same manner, each


Fig. 33.

time that the level of the ink falls to the bottom of the spout, the plunger is let still further down, until at last it touches the bottom of the cylinder. No more ink then remains in the cylinder than is sufficient to fill the space between the plunger and the cylinder to the level of the bottom of the spout.

35. **Canals.** — The methods of conducting a canal through a country which is not a dead level, depends upon the same property of liquids. By the expedients called *locks*, a canal can be conducted along any declivity. If it were cut on an inclined surface, without such an expedient, the water would run towards the lower extremity and overflow the bank, leaving the higher end dry. A channel of any considerable length, having even a gentle and gradual slope, would be attended with this effect. In the formation of a canal, therefore, its course is divided into a series of levels of various lengths according to the inequalities of the country through which it passes; these levels communicate one with the other by locks, by means of which vessels passing in either direction are raised or lowered with perfect ease and safety.

The construction of a lock is easily understood. A ground plan of the part of a canal where a lock occurs is represented in *fig.* 34., and a perspective view of part of the lock is shown in *fig.* 35.

The lock consists of two flood-gates D D and E E (*fig.* 34.). A is

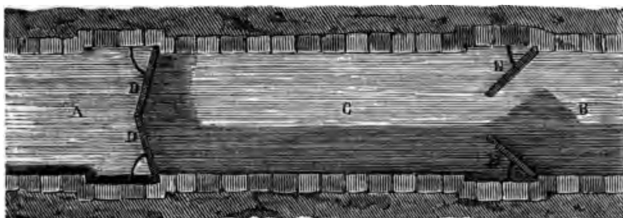


Fig. 34.

the higher level and B the lower one, C being a part of the channel included between the two gates, this part being what is properly called the lock, because when a vessel has been let into it, it can be shut in by closing both pairs of gates. It is obvious that the distance between the gates should be at least equal to the length of the largest vessels intended to pass through them; and if the traffic on the canal be so considerable as to require the passage of more than one vessel at once, the lock should be still larger.

The depth of the lock C should evidently be such that, when the water in it shall be level with the water in the lower level B of the canal, vessels of the greatest draught which pass the canal shall have sufficient water to float them in the dock.

To enable a vessel to mount from the inferior level B, to the superior level A, the gates D D are closed and E E opened, and the vessel is drawn into the lock C, through the gates E E, which are then closed. The level of the water in C being then lower than

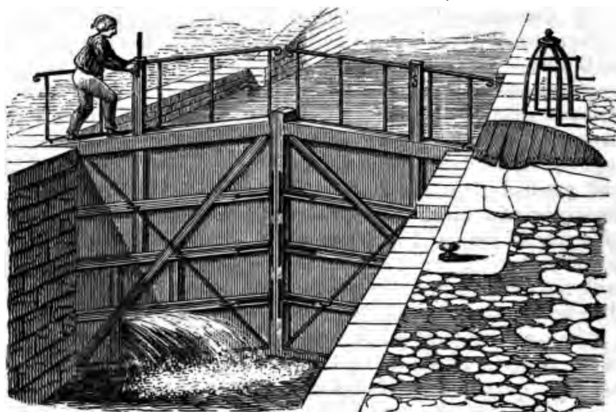


Fig. 35.

that of the water in A, it is necessary to let water flow from A into C, until the lock C is filled to the level of A. But this cannot be done by opening the gates D D; first, because of the great pressure exerted against them by the superior height of the water in A, and, secondly, because the water, rushing in between them, would flood the vessel in the lock. The communication between A and C is, therefore, made by openings near the bottom of the gates D D. These openings are covered by sliding shutters, which are raised and lowered by racks and pinions fixed at the top of the lock, as shown in *fig.* 35., where the lock-keeper is in the act of raising one of them, and the water from the higher level A is seen rushing into the lock C. Since the lower gates E E are closed, the water thus let into the lock, being confined there, will feed it until its level rises to that of the water in A, the vessel being raised with it. When this is accomplished, the gates D D, being subject to equal pressures on the inside and outside, can be opened without difficulty, so that the vessel can pass from the lock C to the upper level A.

To enable a vessel to pass from the upper level A to the lower level B, the process here described is reversed; the gates E E are closed, and the lock being filled by means of the sluices in the gates D D, as above described, the level of the water in C is raised to that

of A, and the gates D D being opened, the vessel is drawn into the lock C. The gates D D are then closed, and the sluices in the gates E E opened; the water escapes through these until the level of C has been lowered to that of B, when the gates E E are opened, and the vessel is drawn out of the lock into the lower level.

It will be evident, from what has been here stated, that for each boat which passes a lock, a quantity of water is necessarily discharged from the higher to the lower level, which is sufficient to fill the lock to a depth equal to the difference of these levels.

When a canal is conducted across an undulating country, its course is necessarily governed by the accidents of the ground, and it alternately rises and falls. In this case, rising by a succession of levels, it necessarily arrives at a certain highest level which is called by engineers, the *summit level*. From this it again descends by a corresponding series of levels. Now, it is evident that, supposing the locks to be all equal in magnitude, the ascent of a vessel will require the descent of as much water from the summit to the lowest level as would fill a single lock; for this quantity of water must be discharged from each lock of the series when the vessel passes through it.

The same may be said of the process by which the vessel descends along the series of locks on the other side of the summit. It appears, therefore, that a supply of water must always be maintained on the summit level sufficient to fill a single lock twice for every vessel which crosses the summit.

It happens fortunately that by the laws of natural evaporation, rain is precipitated in greater quantities on elevated summits than on the intermediate valleys, so that the moving power, in this case, accommodates itself to the exigencies of intercommunication.

36. **Position of the spout of a vessel.** — When vessels containing liquids are supplied with spouts, such as those attached to tea-pots, coffee-pots, kettles, watering-pots, and the like, the extremity of the spout must always be above the top of the vessel when the vessel stands erect, since otherwise the vessel could not be filled; for as soon as the liquid poured into it would raise it to the level of the top of the spout, any more liquid which might be poured in would flow out of the spout.

Liquids are discharged from a vessel having a spout by inclining the vessel in such a manner that the mouth of the spout shall be below the level of the liquid in the vessel.

37. **Levelling.** — One of the most important operations in surveying a country is that by which the inequalities of the ground are determined. These inequalities are measured by expressing their respective heights above or below each other, or above some fixed plane, such as that of the level of the sea.

A levelling instrument consists of a rectangular tube of glass or other material, consisting of three parts, one of which is horizontal, and the other two vertical. This tube being filled, the liquid in the two vertical parts must always be at the same level, and if the eye be directed along these two levels the line of vision will necessarily be horizontal. In the process of sur-

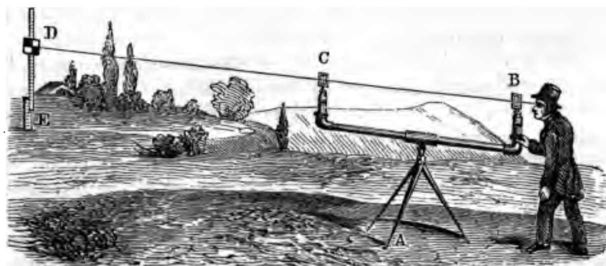


Fig. 36.

veying, the tube is usually supported, as shown in *fig*. 36., upon a triangle A, at a convenient height, to enable the observer to look along the line of levels. Sometimes the eye is directed merely by the surfaces of the liquid in the two vertical tubes; but it is more convenient to place floats upon the liquid which shall support a pair of sights B C, consisting of two thin plates of metal or card, having an opening in their centre, across which two wires are extended at right angles to each other. At a distance from the instrument a staff D is erected, at the top of which there is a similar sight, and which admits of being raised and lowered by two bars, D and E, which slide in contact with each other, and which can be clamped in any desired position. While the observer looks along the line of sights, his assistant by signals raises and lowers the staff until the three sights are brought to the same direction. The three points of sight being then at the same level, the difference of level of the two stations will be the difference of the heights of the sight on the staff, and the sights on the levelling instrument above the ground.

38. **Spirit level.** — This instrument consists of a cylindrical glass tube filled with spirits of wine, except a small space which is occupied by air. The ends are hermetically* sealed to prevent the escape of the fluid.

In whatever position the tube be placed, the bubble of air will rest at the highest point of it. The tube is mounted in

* A glass vessel is said to be hermetically sealed when the opening is closed by melting the glass around it with the blow-pipe.

brass with an opening at the top by which the upper part of the middle of the tube remains visible; the base upon which the tube is fixed is so constructed, that when it rests upon an absolute level surface, the bubble will be included between two brass wires which are carried across the middle of the tube. If the bubble exceed the limits of these wires in either direction, the end towards which it deviates will be the more elevated.



Fig. 37.



Fig. 38.

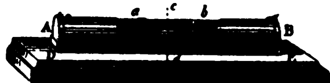


Fig. 39.

Such a level is represented in *figs.* 37., 38., and 39. In *fig.* 37. the glass tube is shown in a separate state with the air bubble at its centre. In *fig.* 38. it is shown invested in its brass case, the figure representing a ground plan. The wires *a b* mark the limits between which the bubble should stand when the surface upon which the instrument is applied is level. In *fig.* 39. the instrument is shown mounted upon its stand D E, the dotted line *c d* representing the centre of the bubble.

39. **Explanation of hydrostatic paradox.** — This property of liquids to maintain their level, when well understood, strips every form of the hydrostatic paradox of that character from which it has taken its denomination.

Let A B C D, for example, *fig.* 40., be a large vessel with perpendicular sides, and communicating by a short tube B E with a vertical tube E F. If water be poured into this vessel, it will rise to the same level in the tube. Now, let us suppose that the water which fills the vessel above the level M N to be removed, and its place supplied by a piston moving water-tight in the vessel; and let this piston be loaded with a weight which shall be equal, including the weight of the piston itself, to the weight of all the water which has been removed. The piston will then press on the water below it with the same force as the water removed previously pressed upon it; and as the water removed was sustained by it, the piston with its load will also be sustained. Thus it appears that this piston is

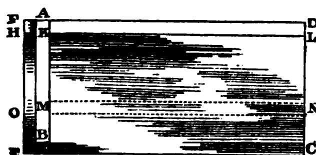


Fig. 40.

supported by the pressure of the column of water H O in the tube E F; and it will be easily perceived that the effect is identical with those of the hydrostatic bellows and the hydrostatic paradox already explained.

40. **Streams, rivers, cataracts, springs, &c.** — The play of the property in virtue of which liquids maintain their level, explains an infinite variety of important and interesting phenomena attending the circulation of water on the surface of the globe. By the natural process of evaporation, the clouds become charged with vapour, and are attracted by the lofty ridges of mountains, and all other elevated parts of the land, round which they collect, and upon which they deliver their contents.

The water thus deposited upon the highest parts of the globe has a constant tendency, by reason of the quality to which we refer, to return to the general level of the sea, and in finding its way thither gives rise to the phenomena of streams, rivers, cataracts, lakes, springs, fountains, and, in a word, to all the infinite variety of effects attending the movement of water which are witnessed throughout the world.

If the waters which fall from the clouds encounter a soil not easily penetrable, they collect in rills, and form streams and rivulets, and descend along the sides of the elevations, seeking constantly a lower level; they encounter in their course, other streams, with which they unite, and at length swell into a river; they follow a winding channel, governed by the course of the valleys and lower parts of the land. Sometimes widening and spreading into a spacious area, they lose the character of a river, and assume that of a lake; then again, being contracted, they recover the character of a river, and after being increased by tributary streams on the one side and on the other, they at length attain their final destination, restoring to the ocean those waters which had been originally drawn from it by evaporation. Throughout the whole of these phenomena, the principle in operation is the tendency of liquids to maintain their level.

But it sometimes happens that the rains on mountainous summits encounter a soil easily penetrable by water. In such cases, the liquid enters the crust of the earth, which it often penetrates to great depths.

Sometimes it encounters strata which are impenetrable, and finds itself walled, so to speak, into a subterranean reservoir. In this case, the liquid is subject to a hydrostatic pressure, arising from the column of water extending from the reservoir to the upper surface, through the veins and channels through which the reservoir has been filled.

This pressure sometimes forces the water to break its way

through the strata which confine it. In such cases, it gushes out in a spring, which ultimately enlarges and becomes the tributary of some river. In other cases, however, the boundaries of the subterranean cistern resist this pressure, and the water is there imprisoned. If the ground above such a cistern be bored to a sufficient depth to penetrate the roof of the cistern, the liquid, having free exit, will rise in the well thus bored until it attain the same level which it has in the channels from which the subterranean cistern has been supplied. If this level be above the surface of the ground, the water will have a tendency to rush upwards, and, if restrained and regulated in its discharge by suitable means, it may be formed into a fountain, from which water will always flow, by simply placing a valve or cock, or from which water may be made permanently to project itself upwards in various forms, so as to produce *jets d'eau.*

If the level of the source, however, be little less than that of the mouth of the pit which has been dug, then the water will rise to such level, and stand there, forming a well. If the original level be considerably below that of the mouth of the pit, then the water will not rise in the pit beyond a certain height corresponding to the level of its source; and in this case a pump is introduced into the pit, and water is raised in a manner which will be explained hereafter.

The preceding observations will be more clearly understood by reference to the diagram, *fig.* 41.

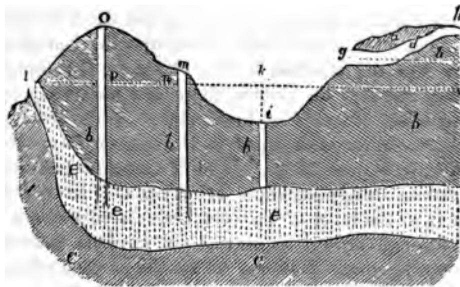


Fig. 41.

This diagram may be considered to represent a vertical section of the strata of the soil, which is penetrated by the pluviose waters, in which *a*, *b*, and *c* represent strata which are impenetrable to water, and *d* and *e* open and porous strata, and crevices which are penetrable.

If we suppose the stratum *d* to reach the surface at *g*, a point

below the level of the highest point *h* of the same stratum, then the water will issue from *g* as from a spring, with a force proportional to the pressure due to the height of the level *h* above the level *g*, deducting, nevertheless, more or less force due to the resistance which the fluid encounters in passing through the soil of the stratum.

If a vertical shaft be sunk at *i* through the impervious stratum *b*, until it enters the stratum *e*, then water would rise in this shaft until it reaches a height *k* corresponding with the level of its highest point *l*; but since this point *k* is above *i*, the mouth of the shaft, the water would spring upwards towards it, forming a jet. If at the mouth of the shaft *i* a valve or cock be placed which can be opened at pleasure, the water would be supplied as required; or if small orifices of any form be placed at the mouth of the shaft, the water would be forced through these so as to form a *jet d'eau*.

41. **Artesian wells.**—It is thus that Artesian wells are formed. Such a spring as that represented at *i* will cause water to rise through pipes, in buildings or elsewhere, to any height not exceeding the level of the line *k l*. If a shaft be sunk at *m*, a point of the surface a little above the level *k l*, and be continued deep enough to enter the stratum *e*, water will rise in this shaft to a point *n* a little below the surface, and will form a well. If the shaft be sunk at a point o considerably above the level of the line *l k*, and be continued, as before, deep enough to enter the stratum *e*, then the water will rise to the point *p* corresponding in its level with *l*, and it will be necessary to raise it to the surface o by means of a pump working in the shaft o *p*.

Water confined in the lower strata of the earth in this manner sometimes bursts its bounds, and rushes into the bed of the sea.

42. **The Rio los Gartos.**—It is stated by Humboldt, that at the mouth of the Rio los Gartos there are numerous springs of fresh water, at the distance of five hundred yards from the shore. Instances of a similar kind occur in Burlington Bay, on the coast of Yorkshire, in Xagua, in the island of Cuba, and elsewhere.

43. **Sudden disappearance of rivers.**—In accomplishing their descent to the level of the ocean, rivers sometimes suddenly disappear, finding through subterranean caverns and channels a more precipitate course than any which the surface offers.

After passing for a certain space thus under ground, they reappear and flow in a channel on the surface to the sea. Sometimes their subterraneous passage becomes choked, and they are again forced to find a channel on the surface. The waters of the Oronoko lose themselves beneath immense blocks of granite at the Raudal dé Cariven, which, leaning against one another, form great natural arches, under which the torrent rushes with immense fury. The Rhone disappears between Fort de l'Ecluse and Seyssel. In the year 1752, the bed of the Rio del Norte, in New Mexico, became

suddenly dry to the extent of sixty leagues. The river had precipitated itself into a newly-formed chasm, and disappeared for a considerable time, leaving the fine plains upon its banks entirely destitute of water. At length, after a lapse of several weeks, the subterraneous channel having apparently become choked, the river returned to its former bed. A similar phenomenon is said to have occurred in the river Amazon, about the beginning of the eighteenth century. At the village of Puyaya, the bed of that vast river was suddenly and completely dried up, and remained so for several hours, in consequence of part of the rocks near the cataract of Rentena having been thrown down by an earthquake.

CHAP. IV.

SOLIDS IMMERSED IN LIQUIDS.

44. **Effects of immersion.** — The immersion, total or partial, of solids in liquids is attended with mechanical effects of great importance in the arts generally, and in navigation more especially.

We shall here exclude all consideration of those cases in which the liquid may act chemically on the solid so as to dissolve it, or in which it may penetrate its pores, so as to modify its mechanical properties. Our observations will be strictly limited to those cases in which the solid is affected neither in its form, dimension, or weight by the liquid.

The immersion, then, of such a solid, be it total or partial, is attended with the following effects which are demonstrated by theory, and verified by experiment:—

1°. It will displace so much of the liquid as is equal in volume to the part immersed.

2°. It will be pressed upwards with a force equal to the weight of the liquid it displaces.

3°. The direction of this pressure will be that of a vertical line, drawn upwards from the centre of gravity of the portion of the liquid displaced.

This force, by which the solid immersed is heaved upwards, is called *buoyancy*.

The centre of gravity of the displaced liquid, is called the *centre of buoyancy*, and the line drawn vertically upwards from that centre, is called the *line of direction of buoyancy*.

The first of the above propositions may be considered as nearly self-evident. If the liquid do not penetrate the surface of the body immersed in it, it must necessarily be displaced by this body,

and the quantity so displaced will evidently be equal to the volume of that part of the solid which is immersed.

If the vessel containing the liquid before immersion were brimful, then the immersion of the solid would cause so much of the liquid to overflow as would be equal in volume to the solid immersed. If the vessel were not brimful, then the surface of the liquid in it would be raised by the immersion of the solid just so much as it would be raised by pouring in so much liquid as is equal in volume to that part of the solid which is immersed.

45. In this manner, the magnitude of solids may be easily measured by immersing them in liquids, and measuring the quantity of the liquid which they displace. Thus, if a solid plunged in a vessel brimful of a liquid, cause ten cubic inches of that liquid to overflow, then it may be concluded that the magnitude of the solid immersed is ten cubic inches.

46. It is difficult directly to measure the volumes of solids, unless they have some regular figure. Liquids, on the other hand, adapting themselves to the form of any vessel in which they are placed, admit of measurement by pouring them into vessels of known capacity. Hence it is that the quantities of liquids are usually expressed by measure, while those of solids are commonly expressed by weight. But by the method just explained, liquids supply easy means of measuring the volumes of solids, no matter how irregular the shape of the latter may be, provided only that the solids to be measured will not dissolve in, or be penetrated by, the liquid in which it is immersed.

47. **Measure of the buoyancy.** — The second of the above propositions, which states that the solid immersed will be heaved upwards by a force equal to the weight of the liquid it displaces, may be demonstrated as follows: —

Let *fig.* 42. be a vessel containing a liquid. If we suppose a part A of this liquid, having any proposed form, to be rendered solid without sustaining any other change in its internal construction or arrangement, such part will still continue at rest since no new force will be introduced to disturb its equilibrium. It is evident that it will have, in virtue of its weight, a tendency to sink downwards in the vertical line through its centre of gravity; but, as it does not sink, it must receive from the surrounding liquid pressures, the resultant of which is a single force equal and opposite to that of its weight, and which, therefore, must be directed upwards in the direction of the vertical line passing through its centre of gravity.


Fig. 42.

We have here supposed the part of the liquid solidified to be below its surface; but all that has been said will be equally applicable to any portion of the liquid taken at the surface.

Now it is evident that if, for the portion of liquid here supposed to be solidified, any solid be substituted, the pressure of the surrounding liquid upon it must still produce the same effect, and such a solid, therefore, whether it be wholly immersed, as shown in *fig.* 42., or partly immersed, as in *fig.* 43., will be affected by a force of buoyancy directed vertically upwards, and therefore at right angles to the surface of the liquid in a line passing through the centre of gravity of the displaced liquid.


Fig. 43.

48. From this it will be easily perceived that a solid will either rise to the surface, sink to the bottom, or remain suspended, according as its weight is less than, greater than, or equal to the weight of its own bulk of the liquid; for, since the pressure upwards is equal to the weight of its own bulk of the liquid, if this pressure exceeds its own weight it will necessarily rise by such excess of pressure; if such pressure be less than its own weight, then it will sink with the excess of its own weight above such pressure; and if that pressure be equal to its own weight, then, the upward and downward tendencies being equal, the body will remain suspended, neither sinking nor rising.

It has been customary to express these effects by stating that a solid submerged in a liquid *loses* so much of its own weight as is equal to the weight of the liquid it displaces, or, what is the same, to the weight of its own bulk of the liquid.

49. **Experimental verification.** — This effect can be verified by experiment. If a body be weighed in a common balance, and afterwards being suspended from the arm of the balance, submerged in the liquid, and again weighed, it will be found that its weight, when so submerged, will be less than its weight before it was submerged by the weight of as much of the liquid as is equal to its own volume.

This experiment may be performed by means of a balance constructed as shown in *fig.* 44., called, from this application of it, the *hydrostatic balance.* The beam is supported by a vertical bar which passes into a hollow column; teeth are formed on each side of this bar, those on the left being connected with a pinion C, and those on the right with a catch D. The lower arm of this catch is pressed outwards by a spring, by means of which the upper end is pressed between the teeth of the bar supporting the balance. When it is desired to raise the beam, the pinion C D is turned in the direction

contrary to the motion of the hand of a watch, and the catch D falls from tooth to tooth of the bar. When the bar is sufficiently elevated, the catch D prevents its descent; but when it is desired to lower it, the catch D is disengaged from the teeth, by pressing its lower arm inwards with the finger, and by turning the pinion C in the direction of the motion of the hand of a watch

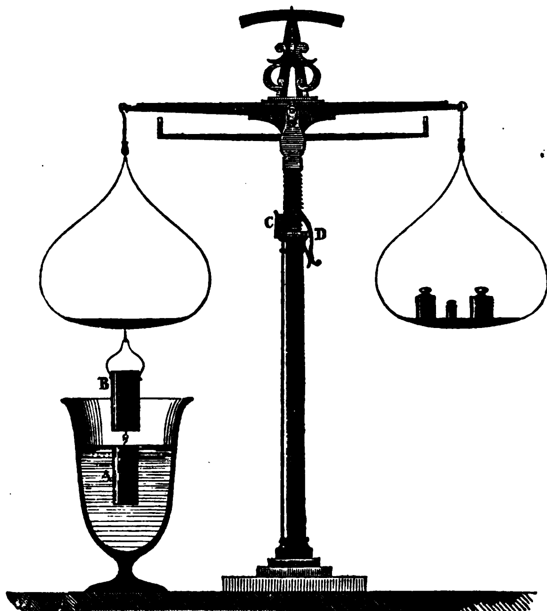


Fig. 44.

To the bottom of one dish of the balance a hollow brass cylinder B is hooked; another brass cylinder A, which may be either hollow or solid, is made to fit exactly into the hollow cylinder B; if A be hollow it may be filled with any heavy matter, so as to vary its weight at pleasure. Let A now be inserted in B, and let it be exactly counterpoised by weights in the other dish; let it be then withdrawn from B, and being suspended from its bottom, as shown in the figure, let it be immersed in the water. The equilibrium will be immediately destroyed, the counterpoising weights preponderating, and the opposite arm of the balance falling down upon a stop placed below to receive it. Thus, the body A will appear to become lighter by immersion in the liquid. Let water be now poured into B, until it is exactly filled: it will then be found that

the equilibrium is restored, the beam again becoming horizontal. It appears, therefore, that the upward pressure exercised upon A, which destroys the equilibrium, is exactly balanced by the weight of the water which fills B, and which is therefore equal in volume to A.

In this experiment, the cylinder A has been supposed to be totally immersed, but the result would be the same if it were partially immersed. Thus, for example, after it has been totally immersed and counterpoised, let the beam be raised by means of the rack and pinion C, so as to draw the cylinder A out of the water through half its length; the equilibrium will then be no longer maintained, and the left hand dish will preponderate. To restore the equilibrium it will be necessary to add to the counterpoising weight in the right hand dish, so much weight as is equal to the weight of the water which had been displaced by that portion of the cylinder A which is now raised above its surface.

It would, however, be an error to infer from this that the weight which the solid in this case seems to lose, is destroyed. It is easy to show that this portion of its weight is supported by the liquid, for if the vessel containing the liquid be weighed with its contents before the solid is immersed, and afterwards, it will be found that after the solid has been submerged, the vessel containing the liquid will be heavier than before by exactly the weight which the solid appears to lose; that is to say, by the weight of so much of the liquid as would fill the space occupied by the solid.

It is therefore more correct to state that when a solid is immersed in a liquid, such a part of the weight of such solid is supported by the liquid as is equal to the weight of so much of the liquid as is equal to the volume of the solid.

50. The hydrostatical principle, in virtue of which a solid submerged in a liquid loses weight equal to that of the liquid it displaces, was discovered by Archimedes. Although this principle is now so generally understood and familiarly known, it is matter of tradition that the discovery made by Archimedes while bathing and reflecting on the effect produced upon his own person by the buoyancy of the water was such, that, frantic with joy, he rushed from the bath through the streets of Syracuse, exclaiming, "Eureka! Eureka!" (I have discovered it! I have discovered it!)

It may, therefore, be inferred generally, that if different solids be immersed either wholly or partially in the same liquid, the weights which they lose, or appear to lose, will be in the exact proportion of their volumes, for they will be the weights of so much of the liquid as is equal to those volumes.

This supplies a method of estimating comparatively the volumes of different solids, these volumes being in the ratio of the weights they lose when submerged in the same liquid.

51. Solids, therefore, can never float if they be heavier, bulk for bulk, than the liquids in which they are immersed.

If they be equal in weight, bulk for bulk, with the liquid, they will sink, until they are totally immersed; but when once they are totally immersed, then, the upward and downward pressures being equal, the solid will neither sink nor rise, but will remain suspended at any depth at which it may be placed.

To verify this experimentally, let a hollow brass ball be provided with a pipe and stop-cock, so as to admit of fine sand being let into it. Let the quantity of sand be first so adjusted that the weight of the ball shall exactly equal the weight of its own bulk of water. If the ball thus prepared be submerged in water, it will float at any depth at which it is placed, neither rising nor sinking; but if the weight of the ball be increased by the addition of more sand, it will sink more and more rapidly as the excess of weight is augmented; and if, on the other hand, its weight be diminished by withdrawing from it a part of its contents, so as to render it less than the weight of its own bulk of water, it will rise more and more rapidly, according as the excess of the weight of its own bulk of water above its weight is greater.

52. It appears from what has been explained, that a solid is buoyant in a liquid in proportion as it is light and the liquid heavy. Thus the same solid is more buoyant in quicksilver than in water; and in the same liquid, cork is more buoyant than lead.

A solid which will float in one liquid will sink in another: thus glass sinks in water, but floats in quicksilver; ebony sinks in spirits of wine, but floats in water; ash and beech float in water, but sink in ether. All these effects are explained by the fact, that in each case the solid sinks or rises according as it is heavier or lighter, bulk for bulk, than the liquid.

53. A block of stone or other heavy substance is more easily raised at the bottom of the sea than the same block would be on land; because, immersed in the sea, it is lighter by the weight of its own bulk of sea-water than it would be on land.

In building piers and other subaqueous works this is rendered manifest. Those who thus work seem endowed with supernatural strength, raising with ease, and adjusting in their places, rocks which they would vainly attempt to move above water. After a man has worked for a considerable time under a diving-bell, he finds, upon returning to the upper air, that he is apparently weak and feeble; everything which he attempts to lift appears to have unusual weight, and the action of his own limbs is not effected without inconvenience.

54. The human body does not differ much from the weight of its own bulk of water; consequently, when bathers walk in water

chin-deep, their feet scarcely press on the bottom, and they have not sufficient purchase upon the ground to give them stability. If they are exposed to a current or any other agitation of the fluid, they will be easily taken off their feet.

When air is drawn into the lungs, the body becomes enlarged by its distension; and when it is expired, the dimensions of the body are again diminished. The weight of the body is so nearly equal to that of its own bulk of water, that this change of magnitude, small as it is, is sufficient to make it alternately lighter and heavier than its own volume of water. When a bather, therefore, inspires so as to fill his chest with air, he becomes, in a slight degree, lighter than water, and his head rises above the surface; when, on the other hand, he expires, the body, contracting its dimensions without changing its weight, becomes heavier than water, and he sinks. Without some action to counteract this oscillation, the alternate sinking and rising would produce inconvenient effects; but this may be prevented by a slight action of the hands and feet, which resists the intermitting tendency to sink.

The facility with which different individuals are able to float or swim varies according to the proportion which the lighter constituents of the body, such as the softer parts, bear to the heavier, such as the bones.

55. A body composed of any material, however heavy, may be so formed as to float on a liquid, however light. The method of accomplishing this is by giving to the solid such a shape that, when immersed in the liquid, some space within the vessel, below the external surface of the liquid, will be occupied by air or some other substance lighter than the liquid.

Thus, if a tea-cup be placed with its bottom downwards in water it will float, and if water be poured into it, it will still float, but it will be found that the surface of the water in the tea-cup will always be below that of the external water, the air which occupies the difference of the levels producing the buoyancy.

A ship may be composed of materials heavier, taken collectively, than their own bulk of water, and nevertheless it floats, because its hull contains air and other substances much lighter than water; but if such a ship spring a leak it will sink.

Vessels laden with cork, certain sorts of timber, and other substances lighter, bulk for bulk, than water, will often become waterlogged, but will still float, because the vessel and the cargo taken together are lighter than their own bulk of water.

An iron boat will float with perfect security, and if it be formed of double plates of metal, enclosing a sufficient hollow space between them, nothing can sink it, so long as such casing remains uninjured.

56. The weight of a vessel including its cargo being equal to that of the water which it displaces, the weight of the cargo can always be determined by the quantity of displacement. If the displacement of the unladen vessel be subtracted from the displacement of the vessel with its full freight, the difference will be the volume of water which is equal in weight to the cargo.

57. The buoyancy of hollow solids is frequently used for the purpose of raising or supporting heavier solids.

Thus bladders are used to support the body in water. Inflated india-rubber bags or belts are used as life-preservers. Hollow boxes or tanks are used for the purpose of raising sunken vessels. These boxes are let down filled with water, and means are provided, when they reach the bottom and are attached by means of diving-bells to the vessels to be raised, of pumping out the water they contain. They thus become empty, and if they have sufficient strength to resist the pressure of the surrounding liquid, and sufficient buoyancy to overcome the weight of the vessel to which they are attached, they will accomplish their purpose.

58. The same experiment is sometimes used to carry vessels over shoals. An East Indiaman, drawing 15 feet of water, has been so much elevated by these means as to draw only 11 feet. The largest vessels of war in the Dutch service were enabled by these means to float over the banks of the Zuyder Zee.

59. The bodies of certain species of animals are much lighter than their own bulk of water. Water-fowl, in general, present examples of this, their plumage contributing much to their buoyancy. Fishes have the power of changing their bulk by the voluntary distension of an air-vessel which is included in their organisation. By these means they can render themselves at will lighter or heavier than their own bulk of water, and rise to the surface or sink to the bottom. As fishes cannot obtain the air necessary for this voluntary inflation from a surrounding medium, they are provided with an apparatus by which they can generate gas for the purpose. This gas is in general not similar to atmospheric air. In such species of fish as live near the surface, it is found to be generally pure azote or hydrogen; in those species which inhabit strata of the deep having a depth of from 3000 to 4000 feet, the gas generated consists of 90 parts of oxygen and 10 of azote.

60. At a depth of 30000 feet, the external pressure would render these gases as heavy as their bulk of water, and consequently the apparatus for generating them would lose its efficiency. In fishes which are drawn up from depths of about 3000 feet, the gas included in this apparatus, which was subject below to an external pressure of 1500 lbs. per square inch, being a hundred times the atmospheric pressure, swells, when brought above the water, to

about a hundred times its original bulk. This produces some curious effects, the internal organs increasing to such an extent that a part of them is driven out of the mouth of the fish, presenting the singular appearance of an inflated bladder.

This circumstance, which is curious and interesting, suggests the probability that the different parts of the sea are each peopled by their inhabitants, varying not only according to climate, but according to depth.

61. When an animal is first drowned, air being expelled from the lungs, the body is heavier than its bulk of water; but when decomposition takes place, gases are generated in various organs, the vessels become distended, and the body becomes lighter than water, and rises.

A solid, having air included, which is exposed to the pressure of the liquid in which it is immersed, may rise to the surface, if it be only sunk to a certain depth; but by sinking it deeper, the pressure of the liquid would condense the air within the solid, so that the weight of the solid, including the air, becomes greater than that of the liquid it displaces, in which case it can no longer rise. A diver who plunges in the sea is lighter when he enters than his own bulk of water; but if he sink to a certain depth, his dimensions will be so contracted by the surrounding pressure, that he will displace a less quantity of water than his own weight, and therefore cannot rise by mere buoyancy, but must ascend by the exertion of his limbs, swimming upwards.

62. In the preceding paragraphs we have only considered the conditions which affect the vertical motion of a solid immersed in a liquid. But it is evident that, without either sinking or rising, a solid may move in a liquid by revolving round some point or line within its own dimensions, as a centre or axis. And even supposing it to be affected by a vertical motion, by which it either sinks or rises, it may at the same time have other motions, by which it turns round some point or line within itself.

From what has been explained, the equilibrium of a solid, whether wholly or partially immersed in a liquid, so far as regards its vertical motion, is established by the condition that it displaces so much of the liquid as is equal to its own weight; but it still remains to show what the condition of equilibrium is, by which a solid will maintain its position in a liquid, without having a tendency to turn round any point or line within it.

If the solid be wholly immersed, as in *fig.* 45., the force which urges it downwards will be equal to its own weight, acting in the vertical line drawn from its centre of gravity downwards; while the force which urges it upwards is the weight of the liquid it displaces, acting from the centre of gravity of that liquid upwards.



Fig. 45.

If the solid be homogeneous, that is, if it have uniform density, its centre of gravity will, in this case, coincide with the centre of gravity of the liquid it displaces; and consequently the two forces which urge it upwards and downwards, acting upon the same point within the body, cannot impart to it any rotatory motion; and the body will accordingly either sink to the bottom, or rise to the surface, or remain stationary without any motion of revolution, according as its weight is greater, less than, or equal to that of its own volume of the liquid.

But if the body be not homogeneous, as will necessarily be the case when it consists of different parts composed of different materials, its centre of gravity will not coincide with that of the liquid it displaces; and in that case the solid may be affected by a motion of rotation as well as a vertical motion.

Let G, *fig.* 46., be the centre of gravity of the solid, and G′ that of the liquid which it displaces; it will then be urged by two forces downwards and upwards, as indicated by the arrows, that is, by its weight acting from G downwards, and by the weight of the liquid it displaces acting from G′ upwards. It is evident that even though the weight of the solid should be equal to that of the liquid it displaces, so that the solid should neither sink nor rise, it would still, in this case, have a motion of rotation, inasmuch as the two forces, which act upon it in contrary directions, though equal, are not directly opposed; and the body will, in fact, turn in the liquid, until G comes directly under G′; it will then be in equilibrium, because the two equal forces, which urge it upwards and downwards, will be directly opposed to each other.

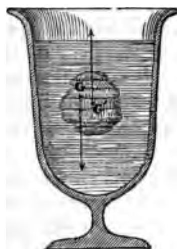


Fig. 46.

But these forces would also be directly opposed, and therefore equilibrium would be produced, if the point G were directly above G′. In short, the two conditions of equilibrium would in general be, first, that the weight of the solid shall be equal to that of the liquid it displaces; and, secondly, that the line G G′, which joins the centres of gravity of the solid and the liquid displaced, shall be vertical.

Consistently with these conditions, therefore, there are two positions of equilibrium, one when G′ is immediately above G, and the other when G′ is immediately below G.

Now, it is easy to see that the former is the position of stable,

and the latter of unstable equilibrium, for upon the slightest disturbance from the position in which G is below G′, it will be brought back to that position by the action of the two contrary forces on G and G′; but if G be above G′, upon the least disturbance from that position, the direction of the two contrary forces, as shown in *fig.* 46., will be evidently such as to cause the solid to turn round in the liquid, until G comes directly under G′.

Let us now consider the case in which the solid is lighter, bulk for bulk, than the liquid, and in which, therefore, it will float partially immersed, displacing so much of the liquid as is equal to its own weight. In that case, also, it will be evident that if the line joining the centres of gravity and buoyancy, (G and G′, *fig.* 46.) be not vertical, the solid will have a motion of rotation, inasmuch as the two equal forces which impel it upwards and downwards will not be directly opposed; but if, as shown in *fig.* 47., the line drawn from G to G′ be vertical, the solid will then be in equilibrium, and that equilibrium will be stable or unstable, according to conditions different altogether from those which determine the equilibrium of solids totally immersed.

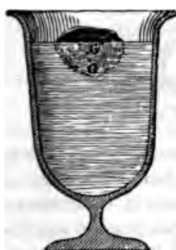


Fig. 47.

Let a cylinder, the length of which is considerably greater than its diameter, be loaded at one end, so as to bring its centre of gravity near to that end; but let it be supposed that its entire weight is less than that of its own bulk of the liquid in which it is immersed; if it be immersed with its heavy end downwards, it will float in stable equilibrium, when it has attained such a depth as to displace its own weight of the liquid; for if it be inclined on one side or the other, as shown in *fig.* 48., the two forces at G and G′ will evidently act in such a manner upon it as to bring it back to the vertical position, the point G being below G′.

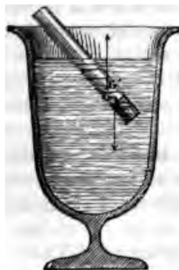


Fig. 48.

But if the same cylinder were immersed with its axis vertical, and its lighter end downwards, the point G would be above G′; and it would be very apparent, by drawing a figure corresponding to *fig.* 48., that in that case the two contrary forces acting at G and G′, instead of having a tendency to bring G back to the position it held over G′, will have a tendency to overturn the cylinder, so as to bring it into the position of equilibrium first supposed.

It appears, therefore, that such a cylinder is in stable equili-

brium when G is directly under G′, and in unstable equilibrium when it is directly over G′.

It must not be supposed, however, that this principle is general. On the contrary, numerous cases are presented in which a floating body is in stable equilibrium when the centre of gravity G is



Fig. 49.



Fig. 50.

directly above the centre of buoyancy G′. Thus, when a solid, whose length and breadth are greater than its thickness, floats upon its flat side, as in *fig.* 49., the centre of gravity G will be directly over the centre of buoyancy G′, and yet the position of equilibrium will be stable; for if the solid be inclined from it on either side, as in *fig.* 50., the centre of buoyancy G′ will take such a position that the two forces which act upon the solid will have a tendency to restore it to the position which it had, which position is, therefore, one of stable equilibrium.

63. In the mathematical theory of floating bodies, a certain point, called the *meta-centre*, is determined, by which the stability of the position of equilibrium is ascertained. If we suppose the floating solid to be in equilibrium, and a straight line to be drawn through the centres of gravity and buoyancy, that line will necessarily be vertical; if then the solid be slightly turned from that position, the line of buoyancy will take a new direction, which will intersect its former direction at the point called the meta-centre; and the equilibrium will be stable or unstable, according as this point is above or below the centre of gravity.

64. **Conditions of stable, unstable, and neutral equilibrium.** — If the meta-centre should coincide with the centre of gravity, the equilibrium will be neutral or indifferent, so that the body will float in any position which is given to it.

65. A sphere of uniform density presents a case of this kind. In whatever position it floats, its centre of gravity being at its geometrical centre, and the part immersed being always a segment of the sphere of precisely the same magnitude, the centre of gra-

vity will necessarily be always at the same level; and, consequently, the sphere will float indifferently in any position in which it may be placed.

It is sometimes said that a floating body, subject to these conditions, rests in stable equilibrium whatever position be given to it; but this is incorrect. The essential character of stable equilibrium consists in the fact that the floating body, if disturbed by any external cause, will recover its former position when relieved from such cause. Now a sphere, or any other body which has neutral equilibrium, will not recover its position after a disturbance, but will remain in the new position which has been given to it. In short, it will remain indifferently in any position, and consequently may be overturned by any force which may be applied to it.

66. The stability of a floating body is susceptible of degrees.

Such a body is more or less stable, according to the force with which it recovers its position of equilibrium after any disturbance. In general, the stability will be increased with the increase of the depth of the centre of gravity of the body below its centre of buoyancy. For this reason, vessels which are appropriated to the transport of passengers, or even of cargoes which are light in proportion to their bulk, require to be ballasted by depositing at the lowest part of the hull, immediately above the keel, a quantity of heavy matter. In packet-ships the ballast used for this purpose is usually iron pigs.

The centre of gravity of a vessel may thus be brought so low as to give it such stability that no lateral force of the wind acting on its sails can capsize it. Hence is explained the necessity of stowing the heaviest part of a cargo in the lowest possible position, and so that its centre of gravity shall be immediately over the keel. By such arrangement any inclination of the vessel would cause the centre of gravity to rise, to accomplish which a force would be necessary proportional to the weight of the vessel, and the height through which such centre would be elevated.

The equilibrium of a boat may be rendered unstable by the passengers standing up in it.

If the centre of gravity of a vessel be not directly over the keel, the vessel will incline to that side at which it is placed, and if this derangement be considerable, danger may ensue. The rolling of a vessel in a storm may so derange its cargo that the centre of gravity might be brought into a position which would throw the vessel on her beam-ends.

67. When the centre of gravity is immediately over the keel, a side wind acting on the sails will incline the vessel the opposite way; this inclination would be much more considerable were it not that the weight of the vessel acting at the centre of gravity

counteracts it, and has a tendency to restore the vessel to the upright position. The several forces which maintain the vessel in the inclined position produced by a side wind may be illustrated as follows. Let A B (*fig.* 51.) represent the position of the vessel; let S represent the point at which the wind acts upon the sail, and let S W represent the direction of the wind. Let E be the centre of gravity of the vessel and her cargo, and let E F be the direction in which her weight acts. Let E′ be the centre of gravity of the water which the vessel displaces, and E′ F′ the direction of the upward pressure. If the effect of the upward and downward forces at E and E′ be considered for a moment, it will be perceived that they have a tendency to incline the vessel to the side opposite to that towards which it is inclined by the wind. By the principles of the resolutions of force, the force S W may be replaced by three others, two of which being equal and directly opposed to the upward and downward forces at E and E′ neutralise them, and the third acting parallel to S W merely carries the vessel sideways perpendicular to its keel, producing what is called *lee-way.*

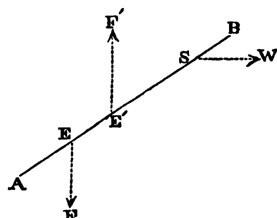


Fig. 51.

68. In sailing-vessels this sideward inclination is a matter of comparatively slight importance, inasmuch as it does not diminish the impelling power of the wind; but in steam-vessels, in which sails are occasionally used, it is attended with considerable loss of the impelling power, one of the paddle wheels being lifted out of the water and the other being almost, if not entirely, submerged. The upright position may, however, be generally maintained by the due management of movable weights placed on the deck of the vessel. In steam-vessels small carriages heavily laden with iron, and furnished with wheels, are usually placed on the deck, and may be rolled from side to side or placed in the middle, so as to regulate the position of the centre of gravity according to the way in which the vessel is affected by the wind. By moving those carriages to the side of the vessel against which the wind is directed, the centre of gravity is moved from over the keel towards that side. Let E (*fig.* 52.) represent the place of the centre of gravity when over the keel, and let G represent the point to which the centre of gravity is transferred by moving the

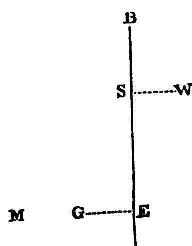


Fig. 52.

carriages to the side of the vessel; let S be the point where the wind acts upon the sail S W: the weight of the vessel acting at G has a tendency to make it incline towards M, and the force of the wind acting at S, in the direction S W, has a tendency to make it incline towards L. These two forces counteract each other, and the vessel maintains its upright position.

69. **Specific gravity.** — The effects produced by the buoyancy of solids, when wholly or partially immersed in liquids, supply the means of determining the comparative weights of each of this class of bodies, considered bulk for bulk.

When substances are compared one with another in reference to their weight, one is denominated heavier or lighter than another, without any special reference either to the bulk or weight of any particular quantity of the substance in question.

Thus, when we say cork is lighter than oak, and mercury is heavier than water, we speak intelligibly, although it be true that a particular mass of cork may be found which is heavier than a particular quantity of oak, and a certain mass of water may be heavier than another particular mass of quicksilver. It is, however, implied in such estimates, that they refer to equal volumes of the two substances which are thus compared as to weight. When we say that cork is lighter than oak, we mean that a piece of cork is lighter than a piece of oak of the same size: and when we say that water is lighter than mercury, we mean the observation to apply to equal measures of the two liquids.

A substance is sometimes said to be heavy or light without express reference to any other substance: thus air is said to be light, and lead heavy. A comparison is, however, here tacitly implied. It is meant that air is lighter, and lead heavier, bulk for bulk, than the average of the substances that fall under common observation. This use of positive terms to express comparative qualities prevails in all applications of language: thus we say of a certain individual that he is very tall, and of a certain house that it is very high; meaning that the man is taller than the average of men, and the house higher than the average of houses.

70. **Absolute and relative weight.** — It appears, therefore, that the term weight is used in two distinct, and sometimes opposite, senses. A mass of cork may be at once very light and very heavy, according to the sense in which the terms are used. A mass of cork which weighs twenty tons is heavy because the absolute weight is considerable. It is, however, in another sense light, because, bulk for bulk, compared with most other solid substances with which we are familiar, its weight is inconsiderable.

The absolute weight of a body is that of its entire mass, without any reference to its bulk; the relative weight is the weight of a

given magnitude of the substance compared with the weight of the same magnitude of other substances. The term weight is commonly used to express the absolute weight, while the relative weight is called *specific gravity*. This denomination of relative weight implies that bodies of different species have different weights under equal volumes. Thus, a cubic inch of cork has a weight different from a cubic inch of oak or of gold; a cubic inch of water contains a less weight than a cubic inch of mercury.

Each different species of body has a different weight corresponding to the same bulk; and hence the name specific gravity, which expresses the weight of a given bulk.

71. **Standard of specific gravity.** — But as specific gravity is a comparative term, it is convenient that some standard should be selected to which all substances may be referred. Water has accordingly been taken, by common consent, as this standard for all bodies in the solid or liquid form. If we say, then, that the specific gravity of quicksilver is 13½, it is meant that the weight of any particular measure of quicksilver is 13½ times greater than the weight of the same measure of water.

But in adopting water as a standard, it is important to consider whether that liquid itself be not subject to variation in its weight. Now it will be shown, hereafter, that every change of temperature which a substance undergoes causes a change in its volume; and water shares in this universal quality. When the temperature is raised, it becomes lighter: a pint of boiling water is lighter than a pint of cold water. If a pint vessel be exactly filled with boiling water, it will be something less than full when it becomes cold, the water contracting its dimensions as its temperature is lowered. In adopting water, therefore, as a standard, it is important that it should be taken at some known temperature.

In some tables of specific gravities, water is taken as the standard at the temperature of 60°, assumed as the average temperature in our climate. There is a further convenience in the adoption of this temperature as that of the standard, since it happens that a cubic foot of water at this temperature weighs, with great precision, 1000 ounces. The numbers, therefore, which express the specific gravities of other bodies with reference to this, will also express the number of ounces which are contained respectively in a cubic foot of their dimensions. Thus, if 13·580 express the specific gravity of mercury, that of water being 1·000, then it will follow that a cubic foot of mercury, at the temperature of 60°, weighs 13580 ounces.

In some tables, however, the standard temperature of water has been taken at 40°, for a reason which will be hereafter explained.

72. Bodies which exist in the aeriform state are so much lighter

than water, that a practical inconvenience would result from taking water as their standard of specific gravity, since the numbers which would then express their specific gravities would be inconveniently small. The standard of specific gravity, therefore, for bodies in the gaseous or aeriform state, is atmospheric air. This form of matter being still more susceptible of change in volume from change of temperature, it is the more necessary in fixing the standard that a certain temperature should be agreed upon. The temperature selected for this purpose has been universally that of melting ice, a point which is independent of the arbitrary scales of thermometers used in different countries.

But as the weight of a given bulk of air depends not only on its temperature, but also upon the pressure to which it is subject, and as this pressure varies within certain limits, it becomes as necessary in fixing the standard of specific gravity to assign a certain pressure as a certain temperature. The pressure generally selected has been that which the atmosphere has when the barometer has the height of thirty inches.

It is therefore to be understood that the standard to which the specific gravities of all bodies in the gaseous form are referred is atmospheric air in a pure state, at the temperature of melting ice, and having a pressure of thirty inches of mercury.

If it be desired to determine the relative weight of any body in the gaseous form in relation to water, it is only necessary to determine the weight of atmospheric air in the standard state in reference to water. Now it has been ascertained that a quantity of atmospheric air, equal in volume to 1000 grains of water, will weigh 1·29 grains; and consequently since a cubic foot of water weighs 1000 ounces, a cubic foot of atmospheric air will weigh 1·29 oz.

73. **Specific gravity of solids.**—The methods of determining the specific gravity of solid bodies are different, according as they are heavier or lighter than equal volumes of water.

74. Let the solid be accurately weighed, and let it then be suspended in pure water and again accurately weighed. The difference between the two weights in water and out of water, will, according to what has been explained, be the weight of a volume of water equal in bulk to the solid. Let the weight of the solid be divided by this weight, and the quotient will be the specific gravity of the solid, that of water being 1·000. Thus, for example, if a solid which weighs 8 ounces, is found to weigh only 6 ounces being weighed in pure water, it will follow that the weight of the water which is displaced, and which is equal to its own volume, will be 2 ounces. Such a solid, therefore, is four times heavier than its own bulk of water, and consequently its specific gravity is 4, that of water being 1.

In like manner, if the weight out of water has been 9 ounces, the weight in water being 7, then the specific gravity would be found by dividing 9 by 2, and would be 4·5.

This method is not practicable for solids which are dissolved when immersed in water. The specific gravities of such solids may be determined by immersing them in some other liquid in which they are not soluble, and determining their specific gravity with reference to such liquid. The specific gravity of this liquid being then determined in relation to water by the methods which will be explained hereafter, the specific gravity of the solid in relation to water will be known. Thus, for example, if the solid in question be five times heavier than the liquid in which it is immersed, and in which it is not soluble, and this liquid be itself twice as heavy as water, then it is clear that the solid will be ten times the weight of its own bulk of water, and its specific gravity would accordingly be 10.

Such solids may, however, be sometimes immersed in water by coating them with a varnish not affected by water. The specific gravities of salts and like substances may thus be found. This method is subject to a slight error, owing to the increased volume produced by the coating, and therefore is not admissible where extreme accuracy is necessary.

If the solid consists of many minute pieces, or be in form of a powder, a cup to receive it ought to be previously suspended in water and accurately counterpoised.

75. When the solid is lighter than water, let it be first correctly weighed, and then attached to another solid also accurately weighed, and which is so much heavier than water that the two solids connected may sink. Let the weight which they lose by immersion be noticed. This will be the weight of as much water as is equal in bulk to the two solids taken together. Let the heavier solid be then immersed, and let the weight it loses be ascertained. If this loss of weight be subtracted from the loss sustained by the combined solids, the remainder will be the weight of as much water as is equal in bulk to the lighter solid. The proportion of the weight of the latter solid to this will determine its specific gravity. Thus, for example, let the weight of the lighter solid be 3 ounces, and that of the heavier solid 15 ounces. Let the weight which the two together lose when submerged in water be 5 ounces, and let the weight which the heavier alone loses when immersed be 1 ounce. Since, then, both together lose by immersion 5 ounces, and the heavier alone loses by immersion 1 ounce, the weight of water equal in bulk to the combined volumes will be 5 ounces, while the weight of water equal in bulk to the heavier alone is 1 ounce.

The weight of water, therefore, which is equal in bulk to the

lighter, must be 4 ounces. But the weight of the lighter solid itself is 3 ounces; therefore it will weigh three quarters of its own volume of water, and, consequently, its specific gravity must be $\frac{3}{4}$, or 0·75; and, by what has been previously explained, a cubic foot of such a solid would weigh 750 ounces.

The specific gravity of a solid lighter than water may also be determined by observing the magnitude of the part immersed when it floats; for when it floats, according to what has been proved, it displaces as much water as is equal to its own weight; consequently, the solid will be just so much lighter, bulk for bulk, than water, as the part of its volume immersed when it floats is less than its entire volume. If, therefore, we divide the part immersed by its entire volume, we shall obtain a fraction which will express its specific gravity.

Thus, for example, if a piece of wood floating on water has half its volume immersed, then it follows that the specific gravity of the wood will be 0·5.

76. To determine the specific gravity of a liquid, let any solid be selected which is heavier, bulk for bulk, than the liquid and than water, and let the loss of weight it suffers by being immersed in the one and in the other be ascertained. This loss will be the weight of so much of the liquid and of so much water as is equal to the bulk of the solid. If, then, the loss of weight sustained by the solid in the liquid be divided by the loss of weight it sustains in water, the quotient will be the specific gravity of the liquid.

For example, let a piece of glass immersed in sulphuric acid lose 3700 grains of its weight, and let the same piece of glass immersed in water lose 2000 grains. It follows, therefore, that the weight of sulphuric acid will be the weight of an equal bulk of water in the ratio of 37 to 20, or $\frac{37}{20} = 1·85$ to 1. If 1000, therefore, express the specific gravity of water, 1850 will express the specific gravity of sulpauric acid.

The specific gravity of a liquid may also be found by means of a solid which is lighter, bulk for bulk, than the liquid and water. Let such a solid be successively floated on the liquid and on water, and let the magnitudes of the parts immersed be observed. These magnitudes will be the volumes of the liquid and of water which are equal in weight to the solid, and, consequently, the specific gravity of the liquid will be found by dividing the part of the solid which is immersed when it floats in water by the part immersed when it floats in the liquid.

For example, if the same solid, floated successively on water and muriatic acid, have the parts immersed in the proportion of 10 to 12, then the weight of muriatic acid will be to the weight of an equal

bulk of water as 12 to 10, and consequently the specific gravity of muriatic acid will be 1·200, that of water being 1·000.

The specific gravity of liquids may also be ascertained by providing a floating body, which can be loaded until a certain known magnitude of it shall be immersed. A float provided with a small disc or cup at its upper part, in which known weights may be placed, serves this purpose. If such a float be placed successively on the liquid whose specific gravity is to be ascertained, and on water, and be so loaded as to have equal parts immersed in both, then the two weights of the float will be the weights of the quantities of the liquid and of water which it displaces.

These weights will therefore be in the proportion of the specific gravities; and the specific gravity of the liquid may be ascertained by dividing the weight of the float in the liquid by the weight of the float in the water.

Thus, for example, if the weight of the float, when immersed in water, be 2000 grains, while its weight, when immersed in sulphuric acid, is 3700 grains, the immersion being the same, then the specific gravity will be ascertained by dividing 3700 by 2000, which will give as the result 1·850.

The most direct method, however, of determining the specific gravity of a liquid is to provide a vessel of known capacity, such as a cubic inch, for example, and of known weight. Let such a vessel be filled with pure water, and weighed; and then filled with the liquid whose specific gravity is to be ascertained, and weighed. If the weight of the empty vessel be subtracted, in each case the remainder will be the weight of the contents, and the comparison of these weights will give, as already explained, the specific gravity.

77. The specific gravity of gases is determined, as has been already explained, by comparing their weights with the weight of an equal volume of pure atmospheric air at a given temperature and pressure. A flask of known capacity is first exhausted by means of the air pump, and then weighed. This flask is then filled with the gas whose specific gravity is to be ascertained, and again weighed. The difference between the weights in the two cases will be the weight of so much of the gas as fills the flask. The weight of atmospheric air itself can be similarly ascertained, and if the weight of the gas be divided by the weight of the same volume of atmospheric air, the quotient will express the specific gravity of the gas in relation to atmospheric air.

It must be observed that in such an experiment the gas must be taken at known pressures and temperatures, since the specific gravities of gases, from their susceptibility of change of density by temperature and pressure, are much more liable to vary than those of solids. The specific gravity, therefore, of gases in general is

determined at the standard temperature of melting ice, and under the standard pressure of 30 inches of mercury.

The instruments for determining specific gravity are the hydrostatic balance, a flask or measure of known capacity, and various forms of floating instruments called hydrometers.

78. **The hydrostatic balance.** — This instrument consists of an ordinary balance, as represented in *fig.* 53., so mounted as to supply convenient means of weighing bodies in and out of liquids. The beam and scales *a b c d* are supported above a stage G H, below which vessels X Y to receive the liquid are placed. The solids are first placed in the scales, and weighed. They are then attached to hooks connected with the bottoms of the scales, and weighed in the liquids, so that the losses of the weight in the liquid can be determined.*

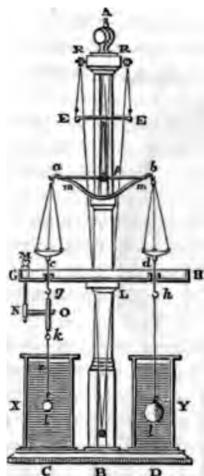


Fig. 53.

79. **Glass flask.**—A glass flask, with an accurately ground glass stopper, serves the purpose of a measure for the determination of specific gravities. The quantity of liquid which it contains, when exactly filled, is easily ascertained; and where extreme accuracy is required, the flask must be reduced to a standard temperature.

80. **Hydrometers.** — Various forms of instruments thus designated have been invented for ascertaining the specific gravity of liquids for the common purposes of commerce. Their indications depend upon the fact that a body, when it floats in a liquid, displaces a quantity of liquid equal to its own weight. The accuracy of these indications depends upon giving them such a shape that the part of them which meets the surface of the liquid in which they float is a narrow stem, of which even a considerable length displaces but a very small weight of the liquid. Thus, any error in observing the immersion produces but a slight effect upon the result.

81. **Sykes's hydrometer.** — This instrument is represented in *fig.* 54. It consists of a brass ball G, the diameter of which is 1·6, into which a conical stem C D, terminating in a pear-shaped bulb, is inserted, and which is so loaded that, being heavier than the rest of the instrument, the graduated stem B A will always remain uppermost and vertical. The instrument is provided with sliding weights W, which will cause it to sink more or less in the liquid.

* For another form of hydrostatic balance see *fig.* 44.

In using the instrument to ascertain the specific gravity of spirits, it is first plunged in the liquid, so as to be wetted to the highest degree on the scale, and is then allowed to rise and settle in equilibrium. The degree upon the scale at the surface of the liquid indicates the magnitude immersed, and by the aid of tables and a thermometer, by which the temperature of the spirits is observed, the specific gravity is computed.

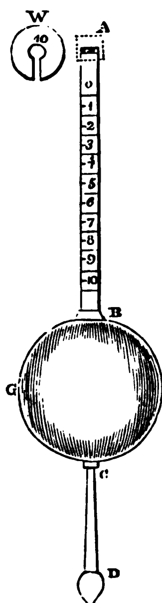


Fig. 54.



Fig. 55.

82. **Nicholson's hydrometer.** — This instrument is represented in *fig.* 55., and is similar in principle to the last, but is provided with a dish C, which is loaded until the instrument is made to sink to a standard point marked about the middle of the stem at D. The instrument is so constructed that the weight of a quantity of distilled water at 60°, equal in volume to the part of the instrument below the standard point, will be equal to the weight of the instrument, together with 1000 grains.

To find the specific gravity of any other liquid, let the instrument float upon it, and let weights be put in the dish C until the standard mark on the stem is brought to the surface of the liquid. The weight of the instrument, together with the weight in the dish,

will then express the weight of the liquid which the instrument displaces. Thus the weight of equal bulks of the liquid and distilled water at the temperature of 60° will be ascertained, and the specific gravity of the liquid may be thence inferred.

83. The power of determining the specific gravity of bodies often supplies the means of detecting other qualities, and sometimes of indicating their component parts, when they are formed of different constituents. Thus spirits, used in commerce and domestic economy, are a mixture of pure alcohol with other bodies, of which water is the principal. The value, therefore, of the liquid depends upon the proportion of pure alcohol which it contains, and this portion is indicated by its specific gravity. In like manner, the precious metals, whether applied to useful or ornamental purposes, are generally alloyed with others of a baser species, the presence and quantity of which would be determined by their specific gravities.

The first attempt to apply the buoyancy of solids to the detection of their component parts, is attributed to Archimedes. It is related that Hiero, king of Syracuse, having bought a crown of gold, desired to know whether the article were of pure metal; and as the workmanship was costly, he desired to accomplish this without defacing it. The problem was referred to Archimedes. The philosopher, while meditating on the solution of it, was bathing. He reflected on the buoyancy of his own body in the water, and then reasoned upon the general effects produced on the weights of solids by immersion. The whole train of reasoning, which has been developed in the preceding pages, passed through his mind. He perceived that by ascertaining the degree of buoyancy which the crown would exhibit when immersed in water, he could ascertain if it were pure gold. It was on this occasion that he rushed forth in a transport of joy, exclaiming, "Eureka! Eureka!"

84. **Standards adopted in different tables.** — Various investigations have been made in different countries, and by different experimental inquirers, with a view to determine and record with precision the specific gravities of bodies. The standard substances invariably adopted, have been water for solids, and liquids and atmospheric air for gases. But these standards have differed one from another in some particulars. Thus, some tables of specific gravities have been calculated with reference to the specific gravity of water at the temperature of melting ice, some at the temperature which determines the maximum density; a condition which will be explained hereafter. This latter temperature is taken at 4° of the centigrade thermometer, which is equal to 39·2° of Fahrenheit's thermometer. The standard temperature has been in some cases taken at 62° Fahrenheit. Similar varieties

have prevailed with respect to the standard temperature of atmospheric air, in which however, also, a standard pressure must be adopted. In some experiments, the standard adopted has been pure dry air, at the temperature of 60°, the barometer standing at 30 inches.

Whatever be the standard adopted in the one or the other class of specific gravities, such tables can be rendered the means of determining, not only the absolute weights of given volumes, but the absolute volumes of given weights of the bodies registered in them, provided that the absolute weight of a given volume of the standard, whatever it be, be known. It is therefore important to indicate the weights of these standards.

85. It has been ascertained that one cubic inch of water at the temperature of 62°, weighs 252·458 grains. It follows from this, that a cubic foot of water under these conditions will weigh 997·137 ounces. It appears from the experiments of Desprez, that between the temperature of greatest density and 62°, the specific gravity of water differs only by one part in a thousand; and, consequently, the weight of a cubic foot of water at 39·2° would be 998·137 ounces.

For purposes, therefore, where the most extreme accuracy is not necessary, it may be assumed, as a convenient standard of calculation, that a cubic foot of water weighs 1000 ounces.

It has been ascertained by recent experiments, that dry atmospheric air at 32° temperature, the barometer standing at 30 inches, is 773·28 times lighter than water.

86. We shall find, therefore, the weight of a cubic foot of air at this temperature and pressure, by dividing the number of ounces in a cubic foot of water by 773·28. It consequently follows that a cubic foot of air at this temperature and pressure will weigh 1·291 ounces, or 564·8 grains.

Since the weight of a cubic foot of water is 1000 ounces, it follows that if the specific gravity of water be expressed by 1000, the numbers which express the specific gravities of all other liquids and solids, will also express the number of ounces contained in a cubic foot of their dimensions. Thus, the specific gravity of gold being 19360, it follows that a cubic foot of gold will weigh 19360 ounces.

By the tables of specific gravities, the volume of any proposed weight of a body can be readily calculated, for it is only necessary to divide the number expressing the weight in ounces by the number expressing the specific gravity, omitting the decimal point; the quotient will express the number of cubic feet in the volume. Thus, for example, if it be desired to ascertain the bulk of a ton weight of gold, it is only necessary to reduce the ton weight to

ounces, and to divide the number of ounces by 19360, and the quotient will be the number of cubic feet in the ton weight.

These methods of calculation will be applicable to all tables of specific gravities, composed with reference to water as a standard.

If it be desired to find the absolute weight of a cubic foot of any of the gases or vapours, whose specific gravities are referred to atmospheric air as a standard, it is only necessary to multiply the number expressing their specific gravity by 564·8; the result will express in grains the weight of a cubic foot of the gas or vapour.

If it be desired to find the volume of any gas or vapour which shall have a given weight, let the weight of a cubic foot be first ascertained by the preceding rule, and let the proposed weight be divided by this weight, the quotient will be the volume in cubic feet.

87. The following tables of specific gravities, taken from the Annuaire of the French Board of Longitude for 1850, contains the most extensive, recent, and correct results of experiments on the specific gravities of bodies: —

TABLE I.

88. *Specific Gravities of Gases at 32° Fahr.; Barom. 30 inches.*

Names.	Specific Gravity by Observation.	Specific Gravity by Calculation.	Observers.
Air	1·000		
Oxygen	1·106	—	Dumas, Boussing.
Hydrogen	0·0691	—	Id. Id.
" carburetted, of the marshes	0·555	0·559	Thomson.
Methyle	—	0·490	
Hydrogen, bicarburetted (olefiant gas)	0·978	0·980	Th. de Saussure.
" bicarburetted, of Faraday	1·920	1·960	Faraday.
" phosphoretted	1·214	1·193	Dumas.
" arseniciretted	2·695	2·695	Id.
Chlorine	2·470	—	Gay Lussac, Then.
Oxyde of chlorine, or hypochloric acid	—	2·340	
Hypochlorous acid of Balard	—	2·980	
Azote	0·972	—	Dumas, Boussing.
Protoxyde of azote	1·520	1·525	Colin.
Deutoxyde of azote	1·0388	1·036	Berard.
Cyanogene	1·806	1·818	Gay Lussac.
Chloride of cyanogene	—	2·116	Id.
Ammonia	0·596	0·591	Biot, Arago.
Carbonic oxyde	0·957	—	Cruikshank.
Carbonic acid	1·529	—	Dumas, Boussing.
Chloro-carbonic acid	—	3·399	
Sulphurous acid	2·234	—	Thenard.
Acid, chlorohydric	1·247	1·260	Biot, Arago.
" bromohydric	—	2·731	
" iodohydric	4·443	4·350	Gay Lussac.
" sulphohydric	1·191	—	Gay Lussac, Then.
" selenohydric	—	2·795	Bineau.
" tellurohydric	—	4·490	Id.
" fluoboric	2·371	—	John Davy.
" fluosilicic	3·573	—	Id.
" chloroboracic	3·420	—	Dumas.
Monohydrate of methyle	1·617	1·601	Dumas, Peligot.
Chlorohydrate of do.	1·731	1·737	Id. Id.
Fluorhydrate of do.	1·186	1·170	Id. Id.

Table II.

89. *Specific Gravities of Vapours reduced by calculation to* 32° *Fahr.; and Barometer* 30 *inches.*

Names.	Specific Gravity by Observation.	Specific Gravity by Calculation.	Observers.
Air - - - - -	1·000		
Bromine - - - -	5·540	5·390	Mitscherlich.
Iodine - - - -	8·716	8·700	Dumas.
Sulphur - - - -	6·617	6·650	Id.
Phosphorus - - - -	4·420	4·320	Id.
Arsenic - - - -	10·600	10·360	Mitscherlich.
Mercury - - - -	6·976	6·970	Dumas.
Acid, arsenious - - -	13·850	13·300	Mitscherlich.
,, anhydrous sulphuric - -	3·000	2·760	Id.
,, selenious - - -	4·030	—	Id.
,, hypo-nitrous - - -	1·720	—	Id.
,, azotic quadrihyd. - -	1·270	—	Bineau.
Yellow chloride of sulphur - -	4·700	4·650	Dumas.
Red do. of do. - - -	3·700	—	Id.
Protochloride of phosphorus -	4·870	4·790	Id.
Chloride of arsenic - - -	6·300	6·250	Id.
Iodide of arsenic - - -	16·100	15·640	Mitscherlich.
Protochloride of mercury - -	8·350	8·200	Id.
Bichloride of mercury - -	9·800	9·420	Id.
Protobromide of mercury - -	10·140	9·670	Id.
Deutobromide of mercury - -	12·160	12·370	Id.
Deutiodide of mercury - -	15·600	15·680	Id.
Sulphuret of mercury (cinnabar) -	5·500	5·400	Id.
Protochloride of antimony - -	7·800	—	Id.
Protochloride of bismuth - -	11·100	10·990	Jacquelain.
Peroxichloride of chromium - -	{ 5·520 5·900 }	5·500	Bineau, Walter.
Bichloride of tin - - -	9·199	8·990	Dumas.
Solid chloride of cyanogene - -	6·390	—	Bineau.
Bromide of cyanogene - -	3·610	—	Id.
Chloride of silicon - - -	5·939	5·959	Dumas.
Camphor - - - -	5·468	5·314	Id.
Essence of turpentine - -	4·763	4·765	Id.
Benzine - - - -	2·770	2·730	Mitscherlich.
Naphthaline - - - -	4·528	4·492	Dumas.
Liqueur des Hollandais - -	3·443	3·450	Gay Lussac.
Sulphuret of carbon - - -	2·644	—	Id.
Alcohol - - - -	1·6133	1·601	Id.
Ether - - - - -	2·586	2·583	Id.
,, acetic - - - -	3·067	3·066	Dumas, Boullay.
,, oxalic - - - -	5·087	5·081	Id. Id.
,, benzoic - - - -	5·409	5·240	Id. Id.
Esprit de bois - - - -	1·120	1·110	Dumas, Peligot.
Sulphate of methyle - - -	4·565	4·370	Id. Id.
Acetate of do. - - -	2·563	2·570	Id. Id.
Potato oil - - - -	3·147	3·070	Dumas.
Acetone - - - -	2·019	2·020	Id.
Mercaptan - - - -	2·326	2·160	Bunsen.
Aldéhyde - - - -	1·532	1·530	Liebig.
Essence of bitter almonds - -	—	3·708	Wohler, Liebig.
Hydruret of salicyle - - -	4·270	4·260	Piria.
Essence of cinnamon - - -	—	4·620	Dumas, Peligot.
,, of cumin - - -	5·200	5·100	Gerb. Cahours.
Acid, acetic - - - -	2·770	2·780	Dumas.
,, benzoic - - - -	4·270	4·260	Id.
,, valerianic - - -	3·680	3·550	Dumas, Stas.
,, cyanhydric - - -	0·947	0·936	Gay Lussac.
Kakodyle - - - -	7·100	7·280	Bunsen.
Oxide of kakodyle - - -	7·550	7·830	Id.
Cyanuret of kakodyle - -	4·630	4·540	Id.
Chloride of kakodyle - - -	4·560	4·800	Id.
Water - - - - -	0·6235	0·624	Gay Lussac.

Table III.

90. *Specific Gravity of Liquids at 39·2° Fahr.*

Name.	Sp. Grav.
Water, distilled	1·000
Bromine	2·966
Mercury at 32°	13·596
Acid, sulphuric, most concentrated	1·841
„ hyposulphuric	1·347
„ fuming azotic	1·451
„ quadrihyd. azotic	1·420
„ azotic of commerce	1·220
„ hypo-azotic	1·451
„ concentrated liquid hydrochloric	1·208
„ acetic monohydrate	1·068
„ acetic, greatest density	1·079
„ oleic	·898
„ cyanhydric	·696
Sulphuret of carbon	1·263
Protochloride of sulphur	1·680
Alcohol, absolute	·792
Do., greatest density (hyd. de Rudberg)	·927

Name.	Sp. Grav.
Ether	·715
„ hydrochloric	·874
„ acetic	·868
Esprit de bois	·798
Potato oil	·818
Acetone	·792
Mercaptan	·840
Essence of turpentine	·869
„ citron	·847
Aldéhyde	·790
Essence of bitter almonds	1·043
Oil of spiræa	1·173
Essence of cumin	·969
„ of cinnamon	1·010
Sea-water	1·026
Milk	1·030
Wine, Bordeaux	·994
„ Burgundy	·991
Olive oil	·915
Naphtha	·847

Table IV.

91. *Specific Gravity of Solids at 39·2° Fahr.*

SIMPLE BODIES.

Name.	Specific Gravity.	Observers.
Iodine	4·948	Gay Lussac.
Sulphur	2·086	Leroyer, Dumas.
Selenium	4·300	
Phosphorus	1·770	
Arsenic	5·670	Herapath.
Carbon { Diamonds	3·530	
	3·500	
Carbon { Graphite	2·500	
Potassium	·865	G. Lussac, Thenard.
Sodium	·972	G. Lussac, Thenard.
Ianganese	8·010	
ron	7·788	
„ cast	7·200	
teel, not hammered	7·810	
inc	7·190	
admium, hammered	8·690	
'in	7·291	
obalt, cast	7·812	
ickel cast	8·279	
„ forged	8·666	
Iolybdenum	8·600	

Name.	Specific Gravity.	Observers.
Tungsten	17·600	Frères d'Echuyart.
Chromium	5·900	
Antimony	6·720	
Titanium	5·300	
Tellurium	6·240	
Uranium	9·000	Bucholz.
Bismuth	9·822	
Lead, cast	11·350	
Copper, cast	8·850	
„ rolled or forged	8·950	
Mercury at 32°	13·598	
Osmium	10·000?	
Iridium (cast by electric battery)	18·680	Children.
Palladium	11·300	
„ rolled	11·800	
Rhodium	11·000?	
Silver, cast	10·470	
Gold, forged	19·360	
„ cast	19·260	
Platinum	21·530	
„ rolled	22·060	

BINARY COMPOUNDS.

Name.	Specific Gravity.	Observers.
Acid, silicic — Quartz hyalin. -	2·653	M.*
Acid, silicic — Agate - -	2·615	M.
Acid, silicic — Opal (sil. hyd.)	2·250	M.
„ hydrated boracic (sassoline) - - -	1·480	M.
Lime - - - -	3·150	Boullay
Chloride of calcium - -	2·230	Id.
Fluoride of calcium (fluor spar)	3·200	M.
Chloride of barium - -	3·900	Boullay
Chloride of potassium - -	1·836	Wenzel
Iodide of potassium - -	3·000	Boullay
Chloride of sodium - -	2·100	Kirwan.
Chloride of ammonia (sal. ammon.) - - -	1·520	M.
Alumina — Corundum, sapphire, and oriental ruby -	4·160	M.
Alumina — Emery - -	3·900	M.
Acid, arsenious - -	3·700	Leroyer. Dumas.
Protoxide of antimony -	5·778	Boullay
Sulphuret of antimony - -	4·334	M.
Oxide of silver - - -	7·250	Boullay.
Sulphuret of silver - -	7·200	M.
Chloride of silver (cast) -	5·548	Boullay.
Iodide of silver (cast) - -	5·614	Id.
Deutoxide of mercury - -	11·000	Id.
Protochloride of mercury -	7·140	Id.
Bichloride of mercury - -	5·420	Id.
Deutiodide of mercury -	6·320	Id.

Name.	Specific Gravity.	Observers.
Protoiodide of mercury -	7·750	Boullay.
Bisulphuret of mercury -	8·124	Id.
Oxide of bismuth - -	8·968	Id.
Sulphuret of bismuth - -	6·540	M.
Sulphuret of molybdenum -	4·600	M.
Acid, tungstic - - -	6·000	M.
Protoxide of copper - -	5·300	Boullay.
Deutoxide of copper - -	6·130	Id.
Protosulphuret of copper -	5·690	M.
Deutoxide of tin - -	6·700	M.
Protosulphuret of tin - -	5·267	Boullay.
Bisulphuret of tin - -	4·415	Id.
Protoxide of lead (cast) -	9·500	Id.
Peroxide of lead - -	9·200	Id.
Iodide of lead - - -	6·100	Id.
Seleniuret of lead - -	7·690	M.
Sulphuret of lead (Galena) -	7·580	M.
Oxide of zinc - - -	5·600	Boullay.
Sulphuret of zinc (blende) -	4·160	M.
Peroxide of iron - -	5·225	Boullay.
Magnetic oxide of iron -	5·400	Id.
Sulphurets of iron — Bisulphuret of iron (pyrites) -	5·000	M.
Sulphurets of iron — Id. (white pyrites)	4·840	M.
Sulphurets of iron — Magnetic pyrites	4·620	M.
Peroxide of manganese -	4·480	Boullay.
Sesquioxide of manganese -	4·810	M.
Red oxide of manganese -	4·722	M.
Protosulphuret of manganese	3·950	M.
Peroxide of titanium (rutiline)	4·250	M.

* M. indicates the numbers taken from the "Traité de Minéralogie" of Beudant. The mean has generally been taken.

SIMPLE SALTS.

Name.	Specific Gravity.	Observers.
Carbonate of lime — Iceland spar -	2·723	Malus.
Carbonate of lime — Arragonite -	2·946	Thenard.
Carbonate of magnesia (giobertite) - - -	2·880	M.
Carbonate of iron (iron spar)	3·850	M.
Carbonate of manganese -	3·550	M.
Carbonate of zinc - -	4·500	M.
Carbonate of barytes - -	4·300	M.
Carbonate of strontian -	3·650	M.
Carbonate of lead (white lead)	6·730	M.
Sulphate of barytes (heavy spar) - - - -	4·700	M.
Sulphate of strontian (celestine) - - - -	3·950	M.
Sulphate of lead - -	6·300	M.
Sulphate of silver - -	5·340	Karsten.
Sulphates of lime — Anhydrite -	2·900	M.
Sulphates of lime — Gypsum - -	2·330	M.

Name.	Specific Gravity.	Observers.
Sulphate of potash - -	2·400	M.
Anhydrous sulphate of soda -	2·630	Karsten.
Chromate of potash - -	2·700	Kopp.
Chromate of lead (native) -	6·600	M.
Nitrate of potash - -	1·930	M.
Nitrate of barytes -	3·185	Karsten.
Nitrate of strontian - -	2·890	Id.
Nitrate of lead - - -	4·400	Id.
Molybdate of lead - -	6·700	Gmelin.
Tungstate of lead - -	8·000	Id.
Tungstate of lime - -	6·000	Karsten.
Aluminate of magnesia (Spinelli) - - - -	3·700	M.
Aluminate of zinc (spinel. zinc) - -	4·700	M.
Silicate of zircon (zircon) -	4·400	M.
Borate of magnesia (Boracito)	2·500	M.

COMPOUND MINERALS, ACCORDING TO BEUDANT.

Name.	Specific Gravity.	Name.	Specific Gravity.
Emerald	2·700	Amphibole { Tremolite	3·000
Garnet	3·350 to 4·240	Amphibole { Actinolite	3·300
Mesotype	2·250	Dolomite	2·800
Idocrase	3·000 to 3·400	Malachite	3·500
Epidote	3·300 to 3·400	Streaked copper	5·000
Triphane	3·190	Copper pyrites	4·160
Chabasite	2·700	Red silver	5·800
Amphigene	2·450	Bournonite	5·700
Feld-spar { Orthose, Albite	2·400 to 2·600	Grey copper	4·300 to 5·000
Stilbite	2·160	Grey nickel	6·100
Tourmaline	3·400	Grey cobalt	6·290
Axinite	3·210	Arsenical iron (mispikel)	6·120
Lazulite	2·900	Alunite	2·690
Ilvaite	4·000	Alum	1·700
Calamine	3·400	Muriated lead (kerasine)	6·000
Crysocale	2·150	Atakamite (muriated copper)	4·430
Peridote	3·400	Cryolite	2·900
Serpentine	2·470	Topaz	3·500
Steatite	2·800	Bismuth tellurium	7·800
Magnesite (écume de mer)	2·500	Auroplumbiferous tellurium	9·220
Pyroxenes { Diopside	3·300	Appatite (chloro-phosphated lime)	3·250
Pyroxenes { Hedenbergite	3·150	Pyro-morphite (chloro-phosphated lead)	7·010
Hypersthene	3·380	Blue phosphated iron	2·660
		Uranite	3·100
		Argentiferous mercury	14·100
		Sphene	3·600
		Wolfram	7·300

VARIOUS SUBSTANCES.

Name.	Specific Gravity.	Observers.	Name.	Specific Gravity.	Observers.
Graphite (the most dense)	2·500	M.	Woods { Pomegranate-tree	1·350	Brisson.
Bituminous coal	1·250	M.	Lignum vitæ, ebony	1·330	Id.
Anthracite	1·800	M.	Dutch box	1·320	Id.
Compact coal	1·330	M.	Heart of oak of 60 years old	1·170	Id.
Charcoal in powder	1·500	Rumford.	Medlar	·940	Id.
Charcoal in pieces, made from { Walnut	·625	Marcus Bull.	Olive	·920	Id.
White oak chestnut	·421	Id.	French box	·910	Id.
American ash	·547	Id.	Spanish mulberry	·890	Id.
Beech	·518	Id.	Beech	·852	Id.
Horn-beam	·455	Id.	Ash	·845	Id.
Wild apple	·455	Id.	Yew	·807	Id.
Sassafras	·427	Id.	Elm	·800	Id.
Virginian cherry-tree	·411	Id.	Apple-tree	·733	Id.
American elm	·357	Id.	Orange-tree	·705	Id.
Virginian cedar	·238	Id.	Yellow fir	·657	Id.
Yellow pine	·333	Id.	Lime	·604	Id.
Birch	·364	Id.	Cypress	·598	Id.
American chestnut	·279	Id.	Cedar	·561	Id.
Italian poplar	·245	Id.	White Spanish poplar	·529	Id.
Ligneous fibre	1·460 to 1·530	Rumford.	Sassafras	·482	Id.
			Common poplar	·383	Id.
			Cork-tree	·240	Id.

VARIOUS SUBSTANCES — *continued.*

Name.	Specific Gravity.	Name.	Specific Gravity.
Yellow amber	1·080	Plaister stone	2·200
Oriental ruby	4·280	Common marbles	2·650 to 2·750
Oriental sapphire	3·990	Marble, Parian	2·830
Brazilian sapphire	3·130	" Carrara	2·720
Oriental topaz	4·000	Building stone, large	1·700 to 1·900
Saxon topaz	3·560	Lias stone	2·250 to 2·450
Oriental beryl	3·540	Basalt	2·450 to 2·850
English flint-glass	3·330	Obsidian	2·300
Glass of St. Gobain	2·380	Volvic stone	2·320
Jasper, onyx	2·800	Alabaster	2·700
Pearls	2·750	Brass	8·300
Coral	2·680	Melchior	7·180
Chinese porcelain	2·380	Bronze for statues and tam tam	8·950
Porcelain clay	2·210	Gun-metal	8·460
Porcelain of Sèvres	2·310	Plumbers' solder	9·550
Millstone flint	2·480	Chinese Tutenague	8·480
Flint	2·600	Ice	·865
Porphyry	2·670 to 2·750		
Granite	2·650 to 2·750		
Slate	2·810 to 2·850		

CHAP. V.

CAPILLARITY, ENDOSMOSE, AND ABSORPTION.

92. INDEPENDENTLY of the phenomena depending on the relative weights of solids and liquids, there are others of great importance, which arise from the molecular attractions manifested between these two classes of bodies.

If a solid be plunged in a liquid, it will be found that in some cases its surface will be wet, and in others perfectly dry. This circumstance arises obviously from the fact that in the former case, particles of the liquid adhere to the surface of the solid so that they do not fall from it by their gravity when the solid is raised from the liquid, while in the latter case, no such adhesion takes place.

If the hand, for example, be plunged in a vessel of water, and raised from it, every part of its surface will be wet; that is, it will be covered by a thin coating of water which adheres to it, and which will not detach itself in spite of the tendency of its gravity to make it fall off. There is, therefore, an attraction between the surface of the hand and the molecules of the water which prevails over the gravity of the latter.

But if the hand be plunged in a vessel of quicksilver, no such adhesion will take place, and the hand, when withdrawn, will be perfectly dry.

The same results would ensue if a plate of iron were successively immersed in water and quicksilver; but if a plate of gold were similarly immersed, it would be wetted by both, and when raised from the quicksilver, would be invested with a white coating of that liquid.

It may then be inferred that an attraction exists between certain solids and certain liquids, which does not prevail to the same extent between others.

93. This class of molecular forces, manifested between solids and liquids, is called *capillary attraction*, or, more generally, *capillarity*. They have received this name from the circumstance of having been first observed, and their laws developed, by means of experiments made with glass tubes, the bore of which was not thicker than a hair, and which were thence called *capillary* tubes, from the latin word *capilla*, which signifies a hair.

If a liquid be poured into a vessel whose sides are of such a nature as to be wetted by it, the liquid, though level at all other parts of its surface, according to the laws of hydrostatics already explained, will be curved upwards near the points where it touches the side of the vessel, as shown in *fig*. 56. But if the sides of the vessel be of such a nature that they would not be wetted by the liquid, the surface will be curved downwards, near the point of contact with the sides, as shown in *fig*. 57.



Fig. 56.



Fig. 57.

94. If two plates of glass, A and B (*fig*. 58.), be immersed in a vessel of water, with their surfaces vertical, and at a certain distance asunder, the water will rise so as to form a concavity upwards at *m* and *n*, where it is in contact with the glass; but at all intermediate points beyond a very small distance from the glass, the level C will correspond with the general level of the surface D and E. But if the plates B and A be brought near to each other, as in *fig*. 59., the two curves *m n* will unite, so as to form a concave surface, and at the

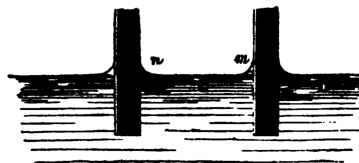


Fig. 58.

same time c will be raised above the general level of the water in the vessel.

If the plates be brought still closer together (*fig.* 60.), the water

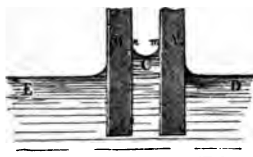


Fig. 59.

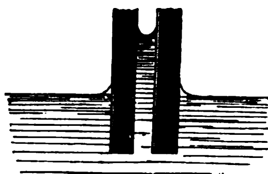


Fig. 60.

between them will rise still higher; the force which sustains the column being augmented as the distance between the plates is diminished.

95. If on the contrary such plates be immersed in mercury, the liquid between them will assume a convex form upwards, and instead of being elevated between the plates, will be depressed, as shown in *fig.* 61.

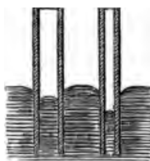


Fig. 61.

96. We have here supposed the plates to be parallel; if, on the contrary, they are inclined one to the other at a small angle, the water will still rise between them, the height to which it rises being greater, according to the proximity of the glass surfaces, and it will form a curve concave upwards, the highest point of which will be at the line formed by the junction of the plates (*fig.* 62.)

If the plates, still inclined one to the other, be placed horizon-

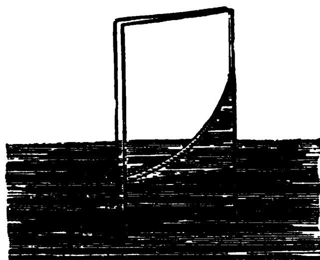


Fig. 62.



Fig. 63.



Fig. 64.

tally, the water included between them, will have both its surfaces concave outwards, as shown in *fig.* 63., and if in this case mercury

be included between them, it will have both its surfaces convex outwards, as shown in *fig.* 64.

All these and many other varieties of the same class of effects may be easily explained by the principles above stated. A full discussion of the mathematical analysis of these capillary phenomena would be unsuitable to the purpose of this volume; but the following general illustration may render them more intelligible.

97. If a liquid be in contact with a solid surface, in a vertical position, a particle, at or near the surface, will be at once solicited by three forces acting in the same vertical plane. First, the gravity of the particle directed downwards; secondly, the molecular attraction of the surrounding particles of liquid, acting from the solid surface, in a direction more or less oblique to it; and thirdly, the molecular attraction of the solid surface itself, directed horizontally from the liquid. Now, according to the relative intensities of these three forces, their resultant will be directed either obliquely downwards and towards the solid surface, or obliquely downwards and from it, or vertically downwards. In the first case, the liquid near the contact of the solid surface will be concave upwards; in the second, it will be convex; and in the third, it will be neither raised nor depressed.

The phenomena will be the same in capillary tubes. A column of water contained in a glass capillary tube will have a concave, and a column of mercury a convex, surface. If such a tube be immersed in water, a column of the liquid will be sustained in it above the general level of the liquid in the vessel. If it be similarly immersed in mercury, the column will be below the general level.

98. The most striking manner of exhibiting this remarkable phenomenon, is by means of a vessel, such as B (*figs.* 65.

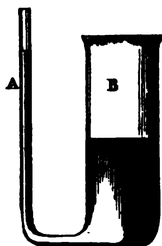


Fig. 65.

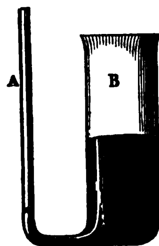


Fig. 66.

and 66.), communicating with capillary tubes A. If water be poured into B *fig.* 65., and mercury into B *fig.* 66., the water will

rise to a higher, and the mercury will be depressed to a lower level than that of the liquid in the communicating vessel B.

Let a series of capillary tubes, gradually diminishing in their bores, be inserted in holes parallel to, and at short distances from, each other, in a small wooden rod, as represented in *fig.* 67. If this be plunged in water and drawn from it, each tube will sustain a column of the liquid, and the heights of each will gradually diminish as the bores of the tubes increase, so that a line drawn passing through the summits of the columns of water supported would form a curve, as represented in the figure.

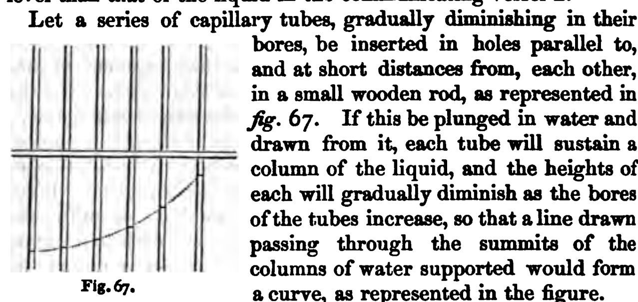


Fig. 67.

99. According to the experiments of Gay Lussac, the ascent and depression of liquids in capillary tubes are governed by the following laws: —

1°. The liquid ascends when it wets the tube, and is depressed when it does not wet it.

2°. The ascent and depression is in the inverse proportion of the diameter of the tube, provided that diameter does not exceed the eighth or tenth of an inch.

3°. The ascent and depression are subject to variation with the nature of the liquid and its temperature. But they are not dependent on the substance or thickness of the tubes, provided the latter are previously wetted.

4°. All the preceding laws prevail when the experiments are made in a vacuum, in the same manner as in the air.

100. In the use of all philosophical instruments in which columns of mercury are supported in tubes of small diameters, the extent of the depression of the mercury, corresponding to the diameter of the tube, requires to be known. The following table, reduced from French measures to English, and resulting from the researches of French observers, will be found useful: —

Diameter of Tube. Hundredths of an Inch.	Depression. Hundredths of an Inch.	Diameter of Tube. Hundredths of an Inch.	Depression. Hundredths of an Inch.
8	17	26	4·0
10	14	28	3·5
12	11	30	3·1
14	9	32	2·8
16	8	34	2·5
18	7	36	2·2
20	6	38	1·9
22	5·2	40	1·7
24	4·5		

101. The laws which govern the ascent or depression of liquids between plates are as follows: —

1°. The ascent or depression is inversely proportional to the distance between the plates.

2°. The height or depression is half of what it would be in a tube whose diameter is equal to the distance between the plates.

If a capillary tube be plunged in a liquid which wets it, and then be slowly raised from it, a drop of the liquid will remain suspended from the lower end of the tube, and the column sustained in the tube will be higher than when the end of the tube was plunged in the liquid. This fact is explained by the supposition that the attraction of the lower end of the tube upon the liquid forming the suspended drop, concurs with that of the glass in contact with the concave part of the liquid at the top of the column.

If a capillary tube, immersed in such a liquid, be broken off at a point below the summit of the column which it supports, the liquid will not overflow, as might be expected, but will collect at the top of the tube, where its surface will become convex. This also is explained by the attraction of the glass at the top of the tube for the liquid, the effect of which is to keep down the stratum of liquid which rests upon it.

If the surface of a body repel a liquid, such a body may, though heavier, bulk for bulk, than the liquid, float upon it, and so present an apparent exception to the general hydrostatic law by which solids which are, bulk for bulk, heavier than liquids, will sink in them.

102. A curious case of this class is found by slightly greasing a fine sewing needle, which may be done by drawing it between the fingers, and then placing it carefully upon its side on the surface of water. Although the needle is, bulk for bulk, heavier than water, it will float.

The explanations which have been given of this curious phenomenon are neither clear nor accordant. It is evident, however, that the effect is produced by the capillary repulsion which exists between the greasy coating of the needle and the water; in consequence of this, the surface of the water is depressed by the needle, which lies upon it in a sort of concave bed. The effect may perhaps be explained thus: —

Let a horizontal stratum of the water be imagined to be taken below the needle, the length of which shall be equal to that of the needle, and the width equal to that of the concave depression in which the needle rests. It is evident that if the weight of this stratum of water, the lower surface of which is plane and horizontal, and the upper surface concave longitudinally, be added to the weight of the needle, their aggregate must be equal to the weight of the water which they would displace if the whole were solid. But this is equivalent to supposing that the weight of the needle is equal to the weight of as much water as would fill the concave bed in which it rests.

103. It is upon the same principle that the power of certain insects (*fig.* 68.) to walk upon water without allowing their feet to sink in it is explained. The feet of these insects, like the needle,



Fig. 68.

have a capillary repulsion for the water, and when they apply them to the surface, instead of sinking in it, they produce depressions upon it.

104. If water be poured into a gauze strainer, it will pass freely through; but if quicksilver be poured into the same strainer, it will be retained as effectually as though the strainer were a solid body. If, however, the bottom of the strainer thus containing the quicksilver be brought into contact with water, the quicksilver will immediately pass through.

It appears from this, that the particles of the gauze, when dry, repel the quicksilver, and that the particles of the latter have a greater force of mutual cohesion than is equal to the gravity of particles having the magnitude of the meshes of the gauze; but that water has not the same repulsion for the quicksilver as the gauze; and accordingly, when the gauze becomes saturated with water, it no longer retains the liquid metal.

105. **The rope pump.** — The instrument thus called depends on the attraction which takes place between the threads of the cord and water. Several endless cords placed close beside each other are extended between two pulleys, one at the top and the other at the bottom of the machine, so that when one of the pulleys is made to revolve, these cords turn, rising at one side and falling at the other. The lower part is submerged in the well from which the water is to be raised, so that a portion of the cords is below the surface of the water. The upper pulley being then made to revolve, the cords at one side descend into the water, and at the other side rise out of it. These are placed so close together, that the water adhering to two adjacent cords, fills the space between them; and thus a sheet of water is raised from the lower to the higher pulley by the ascending cords, and is discharged into a reservoir above.

Examples. — Numerous effects, with which every one is familiar, manifest capillary attraction in a variety of forms.

106. The basement story of a house, and occasionally the ground floor, is often damp because the moisture of the ground ascends through the pores of the materials composing the building, in virtue of its capillary attraction.

If sand, sugar, or other porous body, have moisture beneath it, it will ascend through the pores in opposition to its gravity, being drawn up by the capillary attraction, and the entire mass will become damp.

107. The flame in lamps and candles is maintained by the energy of capillary attraction. The oil, tallow, wax, spirits, or other combustible, rises through the pores and interstices of the wick. When it comes in contact with the flame, it is converted into vapour, and its combination with the oxygen of the atmosphere produces flame.

108. If the end of a towel be immersed in a basin of water, the remainder hanging over its edge, the water will rise from the basin through the pores and interstices of the cloth of the towel, and after a certain time the entire towel will become wet, the water will evaporate from it, and as fast as it evaporates, more water will rise from the basin, and this will continue until the basin is emptied.

109. The porosity in virtue of which solids exert capillary attraction upon liquids, is expressed by the term *bibulous*. Thus, blotting-paper, sponge, soft wood, and other similar bodies are bibulous substances.

110. Wood has a tendency to imbibe moisture by the capillary attraction of its pores. This effect has been adopted with success as an expedient in forming mill-stones. The rock being first cut into the cylindrical form, grooves are formed round it at distances from each other, regulated by the required thickness of the mill-stone. Wedges of dry wood are then driven into these grooves, and left exposed to the dew and other atmospheric moisture. When the wood imbibes this moisture, it swells with such irresistible force as to split the stone in a direction regulated by the groove.

111. The ascent of the sap in trees and other vegetables is in part, though not altogether, due to capillary attraction.

Independent of the agencies of vegetable vitality, capillary attraction unquestionably draws from the ground more or less moisture, though not sufficient for the functions of vegetable life. There is, therefore, in this case, in addition to capillary attraction, a vital agency by which the ascent of the sap is accomplished.

112. It has been proposed, recently, to impregnate timber with saline principles having the effect of preserving it from rot by this

agency. It was proposed to keep the root of the tree, while growing, watered with a solution of the proper salt and other alkaline matter. This solution would then be drawn in, and would rise with the sap, and completely impregnate the tree. When such process should be continued a sufficient time, the tree, being cut down, would be proof against rot.

113. **Endosmose and exosmose.** — A curious class of phenomena, to which these names have been given, was discovered by Dutrochet, about 1826. He found that when different liquids were separated one from another by a partition composed of any membrane or other porous substance, which is penetrable by either of the liquids, two contrary currents will, in certain cases, be established, both passing through the partition, so that a part of each liquid will flow into the other; and it is found, in general, that these currents are unequal, a greater quantity being received by one of the two liquids than that which it transmits to the other. Thus, if the two liquids be called L and L′ (*fig.* 69.), and the partition dividing them M, let the quantity of L which passes through M to L′ be called l, and the quantity of L′ which passes through M to L be called l'. Then in general l and l' will be unequal. Let us suppose that l is greater than l': it is evident in that case that L′, receiving more than it parts with, will be increased, while L, receiving less than it parts with, will be diminished. A stronger current, therefore, will flow through M from L to L′ than that which flows from L′ to L.

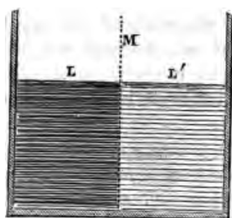


Fig. 69.

The name *endosmose* was given by Dutrochet to the stronger, and *exosmose* to the weaker current; these being derivatives of two Greek words signifying *going in* and *going out*, the movement being referred to the liquid which receives the greater quantity.

This class of phenomena may be strikingly illustrated by the following experiment: —

114. Let a glass vessel be filled to the brim with alcohol, and a piece of bladder, previously well saturated with water, tied over it, so as to be in close contact with the alcohol. Let the vessel thus prepared be sunk in another vessel containing water, so that the bladder shall be below the surface of the water. In the course of a few hours a certain quantity of the water will have penetrated the pores of the bladder, and mixed with the alcohol within it. A certain quantity of the alcohol will have passed through the pores of the bladder, and have mixed with the water in the external

vessel. A less quantity, however, of the alcohol will pass upwards than of the water downwards, and, consequently, the vessel containing the alcohol having more liquid within it than at first, the bladder will become intensely strained, so as to be almost ready to burst. If it be taken out of the water, and pierced with a needle, a jet will issue from it several feet high.

In this case we have supposed the water to press downwards on the bladder within which the alcohol is contained. The same effect, however, would take place if the bladder were presented downwards, and the water pressed against it upwards. The same results would also ensue, if the vessel enclosed by the bladder contained water, and were immersed in a large vessel containing alcohol.

115. **Endosmometer.** — Dutrochet contrived an instrument to which he gave this name, consisting of a bladder, or other membranous bag, into the neck of which a glass tube is inserted, the bladder being tied upon the tube so that no liquid can pass between them. If such a bag be filled with a strong solution of gum or any liquid more dense than water, such as milk, albumen, or a solution of sugar, and then plunged in a vessel of water, the liquid contained in the bag will, after a little time, be observed to rise in the tube, and if the surface of the water in the vessel be not too large, it will be observed to fall, showing that the quantity of liquid in the vessel is diminished, and the quantity in the endosmometer increased. If the liquid in the vessel be examined, it will be found to hold a certain quantity of that substance in solution which was contained in the endosmometer, and if the liquid in the latter be examined, it will be found to be a weaker solution than it was. These facts prove that a certain quantity of the solution has passed into the water, and a greater quantity of the water into the solution. Endosmose has been established from the water to the solution, and exosmose from the solution to the water.

116. Various hypotheses have been proposed to explain these phenomena, none of which, however, has been generally accepted by the scientific world. One of these ascribes the effects to the combination of chemical and capillary attractions. In the case, for example, of the alcohol and water above mentioned, it is assumed that these liquids have a reciprocal chemical attraction, sufficiently strong to cause them to combine if no obstruction intervened. The pores of the bladder exercise capillary attraction, both on the water and on the alcohol; but a stronger attraction on the former than on the latter. If, then, the chemical attraction of the water on the alcohol, and the alcohol on the water, be assumed to be equal, then the greater capillary attraction of the pores of the bladder for the water than for the alcohol, will ex-

plain the fact that more water passes into the vessel containing alcohol than alcohol into the vessel containing water.

Others attempt to explain the phenomena by supposing an electric current having the same direction as the endosmose; others ascribe them to the circumstance of the interposing membrane being more easily permeable by one of the liquids than by the other. Whatever be the cause, it appears certain that capillary attraction must be concerned in it, though it cannot be admitted to be the sole physical agent, inasmuch as an increase of temperature exalts endosmose, while it enfeebles capillary attraction.

117. **Endosmose between gases.** — The effects of endosmose are not confined to liquids. If two gases of different kinds be separated by a perfectly dry membrane, contrary currents will be established through the membrane; but these currents will be equal, so that the phenomenon does not possess the character of endosmose. If, however, the membrane be wet, the currents will be unequal, and true endosmose will be manifested. Let a bladder filled with carbonic acid be enclosed in a glass vessel filled with oxygen. The latter will become charged with carbonic acid, proving that there is endosmose towards the oxygen. In the same manner if we blow a soap bubble, and place it in a receiver filled with carbonic acid, it will soon be inflated to a greater size and will burst.

118. **Absorption.** — The class of effects which have received this name, have a close relation to capillary attraction, and perhaps in some cases to endosmose. If a piece of oak charcoal be placed in a receiver containing gas, it will absorb more or less of the gas: thus, it will absorb 90 times its own volume of ammonia, 35 of carbonic acid, and 9 of oxygen. If it be wetted it will absorb only half of these quantities, showing that its power of absorption depends upon the emptiness of its pores, and must, therefore, be a capillary effect. The absorbing power of deal charcoal is not more than half that of oak, and the charcoal of cork, though extremely porous, does not absorb at al In the same manner the most dense charcoal, presented by the mineral graphite, is equally destitute of absorbing power.

It would appear from this, that the degree of porosity which is compatible with absorbing power has a major and minor limit, disappearing equally when the porosity is too great or too small.

CHAP. VI.

LIQUIDS IN MOTION.

119. **Subject of hydraulics.** — The branch of the mechanical theory of liquids which comprises the investigation of the principles which govern their motion, is called Hydraulics * or Hydrodynamics.

It includes the effects which attend liquids issuing from orifices made in the reservoirs which contain them, or forced by pressure through tubes or apertures in pipes or in channels; it includes also the motions of rivers and canals, and the resistances produced by forces, developed by the mutual impact of liquids and solids.

120. **Velocity of efflux from an orifice.** — If a small hole be made in the side of a vessel which contains a liquid, it rushes from it with a certain velocity, depending on the pressure at the point where the orifice is made. Since this pressure is the cause which imparts the moving force to the fluid, it will necessarily be proportional to such momentum. But this momentum is, according to what has been already established, proportional to the quantity of liquid which is put in motion, and to the velocity imparted to it, and is expressed by multiplying the quantity of liquid which escapes from the orifice in a second by the velocity with which such liquid is moved. Now the column of liquid which passes from the orifice in a second is that whose base is the area of the orifice, and whose length is equivalent to the velocity with which the fluid passes through it; since it is evident that so much of the fluid as passes through the orifice in a second would form a column whose base is the orifice, and whose altitude is the space through which the fluid moves. The effect may not inaptly be illustrated by the process of wire-drawing, in which the metal is forced through a circular orifice. The quantity of metal which passes through in a second would be determined by the area of the orifice and the velocity with which the wire is drawn. If, then, we multiply the area of the orifice by the velocity with which the fluid passes through it, we shall obtain the total quantity of fluid which is discharged in a second. Thus, if the area of the orifice be expressed by o, and the velocity with which the fluid passes through the orifice by v, then the total quantity of fluid discharged in a second

* From ὕδωρ (hudor), *water*, and αὐλός (aulos), *a pipe*.

will be expressed by $o \times v$. But this quantity, being moved with the velocity v, has a moving force which will be expressed by multiplying it by the velocity, and therefore will be $o \times v^2$.

121. By the velocity of efflux must be understood *the quantity of liquid discharged from the orifice per second*, while the velocity of the liquid in issuing from the orifice is measured by the *space through which the liquid would move in a second*, or, what is the same, as has been just explained, the length of the column or vein of liquid which passes through the orifice in a second. If, then, E express the velocity of efflux, or the total volume of liquid discharged in a second, we shall have $E = o \times v$.

Since the moving force with which the quantity expressed by E is propelled is found by multiplying the quantity E by the velocity with which it is moved, this moving force will be E multiplied by v. But since $E = o \times v$, we must have $E \times v = o \times v^2$.

It appears, therefore, that the moving force impressed per second on the liquid discharged *is proportional to the area of the orifice multiplied by the square of the velocity.*

For orifices of equal magnitude, therefore, the moving force imparted to the liquid will be in the ratio of the squares of the velocities with which the liquid is propelled.

122. **The square of the velocity in escaping from the orifice proportional to the depth.** — But it has been already shown that the moving force imparted to the liquid escaping from the orifice is proportional to the pressure of the liquid at the orifice. This pressure, however, is proportional to the depth of the orifice below the surface of the liquid in the vessel, and consequently it follows that the squares of the velocities of the liquid in passing through the orifice are proportional to the depth.

Thus, if several orifices be made in a vessel containing a liquid at the depth of 1, 4, 9, and 16 feet, the velocities with which the liquid will escape from these will be in the proportion of 1, 2, 3, and 4.

This reasoning shows the manner in which the velocity varies with the depth; and if the velocity corresponding to any particular depth were known, the velocities at other depths could be found. Thus, if the velocity at the depth of 1 foot below the surface were known, then the velocity at 9 feet depth would be three times the former; the velocity at 16 feet would be four times that velocity, and so on.

123. **Velocity of efflux is that which a body would acquire in falling from a height equal to the depth.** — Thus, for example, it is known that a body falling freely through the height of 193 inches, would acquire a velocity which, if continued uniform, would cause it to move through $193 \times 2 = 386$ inches per second.

Now, if an orifice be made in a vessel containing a liquid at the depth of 193 inches below the surface, it will be found that the liquid will flow from such orifice with the velocity of 386 inches per second.

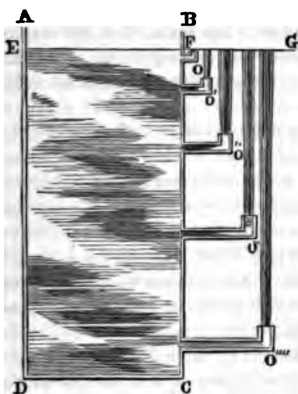


Fig. 70.

124. **If the liquid escape by a jet directed upwards, it would rise to the level of the surface, if not resisted by the air.** — In *fig.* 70., o, o′, o″, &c., represent pipes of discharge inserted in a vessel containing a liquid, having their openings turned upwards. The several jets which would escape from these orifices would, if no disturbing force intervened, rise to the level E F G of the liquid in the vessel, as represented in the figure. This, however, as well as the premises from which it is deduced, requires to be submitted to considerable modification before it can be applied in practice.

125. In the preceding investigation we have considered the orifice to be indefinitely small, so that every part of it may be taken to be at the same depth below the surface. If it be not so, the point which determines the velocity would be its centre. We have also considered the fluid in issuing from it as subject to no resistance proceeding from its sides, which will necessarily be the case, if the side of the vessel has any considerable thickness. This cause may be in part obviated by making the side of the vessel at the place where the orifice is made extremely thin.

In fine, the jet issuing from the orifice is supposed to move freely in vacuo; instead of which, in fact, it encounters the resistance of the air, which not only diminishes the velocity, but scatters it.

We have also considered that the jet of liquid issuing from the orifice has the form of a cylindrical rod, the orifice being supposed circular, the thickness of this cylinder corresponding with the magnitude of the orifice.

126. **The contracted vein.** — Now it was shown by Newton, that a jet issuing from a circular orifice made in the thin side of a vessel is not of a cylindrical form; that, in fact, the fluid does not issue from such an orifice, as a small wire would do from the hole through which it is passed in the process of wire-drawing. Newton showed, on the contrary, that the jet, immediately on leaving

the orifice, contracts its dimensions, and that at a distance equal to the diameter of the orifice itself this contraction attains its limit, and that the section of the jet at this point will be about two thirds of the magnitude of the orifice. It was held by Newton, and assumed by others since his time, that beyond this point the section of the jet was enlarged, so as take the form of a diverging cone. The point of greatest contraction is called by Newton, and has since been denominated, the *vena contracta*, or *contracted vein*.

The cause of this remarkable phenomenon may be traced to the fact that the liquid contained in the vessel rushes from all sides towards the orifice, so as to form a system of converging currents, as shown in *fig.* 71., where *a b* indicates the diameter of the orifice. The convergence of these currents continues for a certain distance from the orifice, after which it ceases. If the diameter *a b* of the orifice be supposed to be divided into ten equal parts, the distance *e f* of the contracted vein from the orifice will be five, and its diameter *c d* eight of these parts; and since the superficial magnitudes of circles are in proportion to the squares of their diameters, it follows that, if the entire area of the aperture *a b* is supposed to consist of 100 parts, the area of the contracted vein at *c d* will consist of 64 of these parts.

Now it is evident that since the same quantity of liquid which flows in a given time through the opening *a b*, must flow in the same time through the smaller area of *c d*, its velocity in passing through the contracted vein must be greater than that with which it issues from the opening *a b*, in exactly the same proportion as the area of *a b* is greater than that of *c d*; that is, in the ratio of 100 to 64.

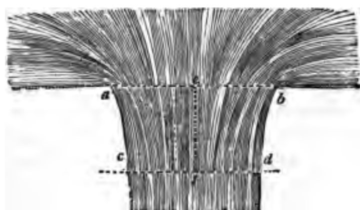


Fig. 71.

In the application, therefore, of the formula given above for determining the velocity of efflux, it is most necessary to establish a distinction between the motion of the liquid in flowing through the orifice, and its motion in passing the contracted vein.

It has been shown that, theoretically, the velocity with which the liquid would escape from the orifice, is that which a heavy body would acquire in falling freely from the level of the surface of the liquid to the level of the orifice; but the actual effects are not found to correspond with this. The velocity of the fluid in issuing from the orifice being less than that due to the height of the surface of the fluid above the orifice, in the proportion of 64

to 100, and this being the exact proportion of the area of the contracted vein to that of the orifice, it follows that the velocity of the fluid, in passing the contracted vein, is exactly that which a body would acquire in falling freely from the level of the surface in the vessel to that of the orifice.

127. **Theoretical and practical efflux.** — It will be evident, therefore, that the actual velocity of efflux will be less than that which is calculated by the formula given above, since that formula is based upon the supposition that the velocity of the fluid in issuing from the orifice is greater, in the proportion of 100 to 64, than its true value.

The efflux, computed by the preceding formula, taking o to express the area of the orifice, is called the *theoretical efflux*.

The same formula, however, would express the practical efflux, if o, instead of expressing the area of the orifice, were understood to express the area of the contracted vein, or, more simply still, the actual efflux may be obtained by diminishing the theoretical efflux, in the proportion of 100 to 64.

In *fig*. 71. the orifice is represented as being made in the bottom of the vessel; but as the pressure of the liquid is produced with equal intensity in all directions, the form and position of the contracted vein will be the same whatever be the position of the surface of the vessel in which the opening is made. It must be understood that the part of the vessel through which it is made has no sensible thickness.

128. **Savart's experiments.** — Recent experimental investigations, however, made by Savart and others, have proved that the phenomena are not in strict conformity with Newton's theory. It is true that the jet contracts its dimensions in issuing from the orifice, and arrives at the limit of its contraction at a distance from the orifice equal nearly to its own diameter.

Savart has shown that in all cases, except when the jet is discharged upwards, its section goes on diminishing, though much less rapidly, until it loses its form and is scattered by the resistance of the air. Thus the contraction is at first rapid, and the form of the jet is decidedly conical from the orifice to the contracted vein; but beyond that point the jet has very nearly the form of a uniform rod of glass, having a tendency, however, to become still thinner.

Our limits will not allow us to enter into the details of the curious phenomena developed in the researches of Savart. It may not, however, be uninteresting to reproduce some of his diagrams, showing the form of jets. *Fig*. 72. represents a jet which issues from the bottom of a vessel at *a*, such as it appears to the eye. From

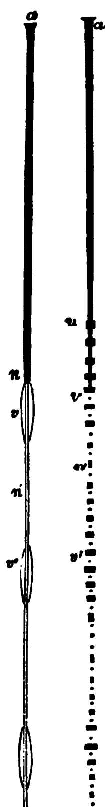


Fig. 72. Fig. 73.

a to *n* it has the appearance of a uniform and straight glass rod; at *n* it begins to lose its transparency, and also to change its form, swelling and contracting alternately, and at unequal intervals. When this part of the jet, however, was examined with greater precision, it was proved to consist of, not a continuous stream of liquid, but a series of distinct and separate drops, as represented in *fig.* 73.; the dilated parts, represented at *v* and *v'*, *fig.* 72., were formed by large drops, which were dilated horizontally, while the nodes *n*, *n'* were formed by the same drops dilated vertically. Thus it appears that in their descent the drops were subject to a pulsation, by which they alternately enlarged and contracted their dimensions vertically and horizontally; but it was also proved, that besides these drops there were other similar drops, represented by the dots in *fig.* 73., which did not change their form. The pulsations attending these alternate changes of form of the drops produced a distinct sound. When a musical sound of the same pitch was produced near the jet, these alternate pulsations of the drops became more regular. It was further proved by these curious researches, that the pressure of the air has no influence on these phenomena.

129. **Effect of an ajoutage.** — In the preceding paragraphs the liquid is supposed to escape through an orifice made in the side or bottom of the vessel containing it, the borders of the orifice being understood to have almost the sharpness of a knife. The phenomena are, however, most materially modified if the liquid escapes through any kind of tube inserted in the orifice; such a tube is called an *ajoutage*.

If the ajoutage be cylindrical, as represented in *fig.* 74., the liquid passing through it will be prevented from forming a contracted vein, and will issue in a column having everywhere the full diameter of the ajoutage. It might therefore be inferred that the actual velocity of efflux would be equal to the theoretical velocity. This, however, will not be the case; for, although the efflux is not diminished by the contracted vein, there is nevertheless a diminution, owing to the force lost by the collision



Fig. 74.

of the liquid currents within the vessel in approaching the orifice. The practical efflux in this case is found, therefore, to be less than the theoretical, in the proportion of 82 to 100; while, without the ajoutage, it would, as we have seen, be less, in the proportion of 64 to 100.

If the ajoutage, instead of being a cylindrical tube, as in *fig.* 74., be a conical tube, contracting towards the mouth, as represented in *fig.* 75., an increase more or less considerable will be produced in the velocity of efflux, according as there is a greater or less difference between the internal diameter C D, and the external diameter A B of the ajoutage. It has been found that when the angle of contraction of the ajoutage is about 13° or 14°, as represented in the figure, the practical efflux is not more than 5 per cent. less than the theoretical.

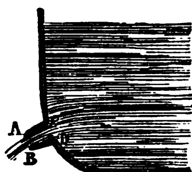


Fig. 75.

If the ajoutage, instead of being formed as a converging, is formed as a diverging cone, as shown in *fig.* 76., a curious and unexpected result is obtained, the actual being greater than the theoretical efflux. This phenomenon might be explained by assuming that the real orifice in this case is the external, and not the internal diameter of the ajoutage. The practical efflux, however, is greater than the theoretical efflux due to the internal diameter, and less than that due to the external.

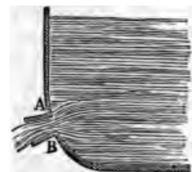
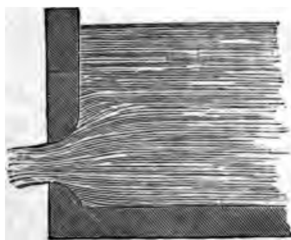


Fig. 76.

When the side of the vessel in which the orifice is made has any considerable thickness, the velocity of efflux will be augmented, whether an ajoutage is used or not, by giving to the borders of the opening a curved form, as represented in *fig.* 77. The currents of the liquid, urged towards the opening, will in this case follow the flexure of the sides of the opening, and a less portion of their force will be lost by their mutual collision.


Fig. 77.

130. **Motion of liquids in pipes and channels.** — If a pipe or channel have everywhere the same transverse section, it is evident that the velocity of the liquid in passing through it will be

everywhere the same. But since the same quantity of liquid must pass in a given time through the same length at every part of it, if it have a variable transverse section, the velocity of the liquid will be less in exactly the same proportion as the transverse section is greater. In general, if the same volume of liquid be driven through pipes or canals of unequal sections in the same time, its velocity in moving through them will be in the inverse proportion of the areas of the section.

This is a fact familiar to every one who observes the course of rivers: wherever the bed contracts, the current becomes rapid; and where, on the contrary, it widens, the stream becomes more sluggish.

The force of currents, whether in pipes, canals, or rivers, is more or less resisted, and their velocity retarded, by the friction which takes place between the liquid and the solid surfaces of the pipe or canal with which it moves in contact. This effect is somewhat complicated, the retarding friction being produced more immediately between the liquid and the solid, but also between one part and another of the liquid itself. The parts of the liquid in immediate contact with the surface of the pipe or canal are directly retarded by the friction of that surface; but these parts themselves react, by their own friction, on others within them and in contact with them, so as to retard these others, though in a less degree. These last react in like manner upon others nearer the centre, and so on.

Thus it appears that the effects of the friction of the solid surfaces are propagated successively through the parts of the liquid itself inwards towards the centre, so that the several parts of the liquid move with velocities increasing gradually from the surface of the pipe or canal to the centre.

This explains a fact which may be observed in all rivers: the velocity of the stream being always greater in the centre than near the banks.

131. When we speak, therefore, of the velocity of a liquid moving in a pipe or tube, or that of a river or canal, we must be understood to express neither the greatest velocity of the central parts, nor the least velocity of the borders, but the mean velocity of the whole. Now, this mean velocity at any given point will be easily found, if the actual volume of liquid which passes through a section of the pipe or channel in a given time be known. Thus, for example, if the section of the channel be 20 square yards, and if it be known that 1000 cubic yards of liquid pass the section per minute, it will follow that the mean velocity with which it moves through the section will be 50 yards per minute.

132. It has been ascertained that the resistance to the motion

of a fluid, produced by the friction of the solid surfaces of the pipe or canal through which it flows, increases in a certain proportion with the velocity, and also with the extent of the surface with which it is in contact, other things being the same.

In this respect it will be observed that the effects of the mutual friction of a fluid and solid differ from those of two solids, since it has been shown that the latter are nearly, if not altogether, independent both of the velocity and of the surface of contact.

It follows, from what has been stated, that the force necessary to impel liquids through tubes or channels will be less in proportion as their transverse section is greater, as well because in that case the surfaces of contact are less, as because the velocity necessary to send through them a given volume of liquid is also less.

133. Another source of resistance to the motion of liquids, whether in pipes or channels, arises from variations in their direction; the greater such changes are, and the more suddenly they are produced, the greater will be the retardation consequent upon them. If a pipe conveying a liquid has upon it an elbow like that which is often placed upon stove-pipes, the current, in passing it, suffers a considerable retardation. This effect may be diminished, though not removed, if the desired change of direction be produced by a curve instead of by an angle.

134. The effect of elbows, though much less considerable in smoke funnels than in water pipes, inasmuch as the smoke and heated air are so much lighter than the water, is nevertheless not without injurious effects upon the draught.

135. When it is desired to check the flow of fluids through pipes, the object is attained, in the case of water pipes, by stopcocks, which, being turned as shown in *fig.* 78., so as to compel the liquid to pass two successive angles, besides contracting the section of its course, call into action two causes of retardation.

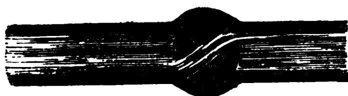


Fig. 78.

In steam pipes the same effect is produced by an expedient called a *throttle-valve*, which is a circular plate of metal turning on an axis passing through its centre across the pipe, by means of which the flow of steam may be either wholly obstructed by turning against it the flat side of the valve, or wholly unimpeded by presenting to it the edge of the valve.

This arrangement is represented in *figs.* 79. and 80. A section of the valve is shown in *fig.* 79., where T is the valve turning on its axis, and in a position intermediate between that which

would altogether stop the flow of steam, and that which would leave it unimpeded. A front view of the valve is shown in *fig.* 80., where C B is the handle outside the tube, by which the valve can be turned

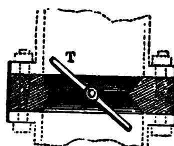


Fig. 79.

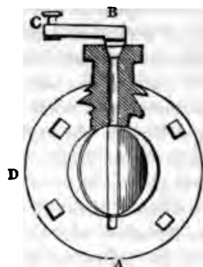


Fig. 80.

136. **Ornamental waterworks.**—The effects of the various forms of *jets d'eau*, by which artificial fountains are constructed, depend altogether on the principles which have here been explained. The reservoirs from which the water is supplied are always established upon an elevation, the level of which is considerably higher than that of the fountains. The pipes conducting the water from the reservoirs are of such dimensions as are capable of supplying the necessary quantity of water in a given time, and so as not to diminish its force injuriously. The *jets d'eau* are produced by inserting, at proper places in the ornamental works of the fountains, *ajoutages* in directions proper to produce the desired effects. Theoretically, the water issuing from a vertical *jet d'eau* ought to rise to the level of the reservoir, but it is prevented from rising even nearly to that elevation by the loss of force due to the various causes which have been explained.

It will be evident, from what has been stated, that the less distant the reservoirs are from the fountains, the less force will be lost; circumstances, nevertheless, sometimes render it unavoidable to establish them at a considerable distance. Thus the celebrated waterworks at Versailles are supplied from an artificial reservoir erected on the heights of Marly. This reservoir is filled with water driven into it by a steam-engine erected on the banks of the Seine, through a large iron pipe carried up to it upon an inclined plane.

The waterworks of the Crystal Palace, Sydenham, are supplied from a reservoir erected in the gardens at a considerable altitude above the level of the fountains. This reservoir receives its supply, by means of a steam-engine, from a well sunk in the gardens.

137. **The ball-cock, or self-acting feeder.** — In many processes, as well in scientific researches as in the industrial arts, it is necessary to maintain the water contained in a vessel or reservoir at an invariable level, notwithstanding that it is subject to a constant discharge, either by a discharge pipe, by evaporation, or any other cause. A class of contrivances called *self-acting feeders* is commonly used for this purpose. These consist of a float, which rises and falls with the surface of the water required to be maintained at a constant level. This float is connected by some means with a valve or cock, in a pipe which leads from a feeding cistern to the reservoir in which the constant level is to be maintained. As the float falls, it opens the valve or cock, and as it rises, closes it, admitting water from the feeding cistern in one case, and excluding it in the other. In general it adjusts the valve or cock, so that a stream of water flows in which is equal in quantity to that which flows out or is consumed in evaporation.

One of the forms of this expedient is shown in *fig.* 81., where F is the float connected by a wire with a lever D, to the opposite arm of which is attached another wire connected with the valve V, in a pipe leading from the feeding cistern C, to the reservoir in which a constant level is to be kept. The float F so adjusts itself that the valve V is opened just sufficiently to let as much water flow in per minute as is discharged in the same time.

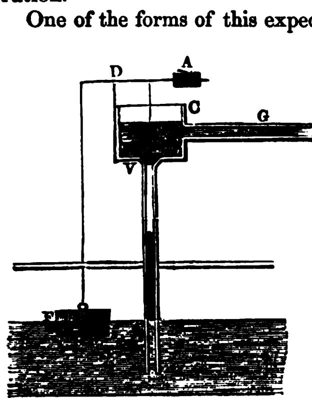


Fig. 81.

Another form of self-acting feeder is shown at *fig.* 82. In this case a valve is placed at the point where the pipe leading from the feeding cistern enters the reservoir in which a constant level is to be maintained. A rod attached to this valve is connected with the extremity of an arm C B (*fig.* 82.) of a lever C B A, to the opposite arm of which a large and hollow ball of copper is attached. When the level of the water rises, the ball A is elevated by its buoyancy, and with it the arm A B; and consequently the arm B C is lowered, and the valve closed.

As in the former case, the valve becomes so adjusted that a continuous stream is admitted, equal in quantity to the water discharged.

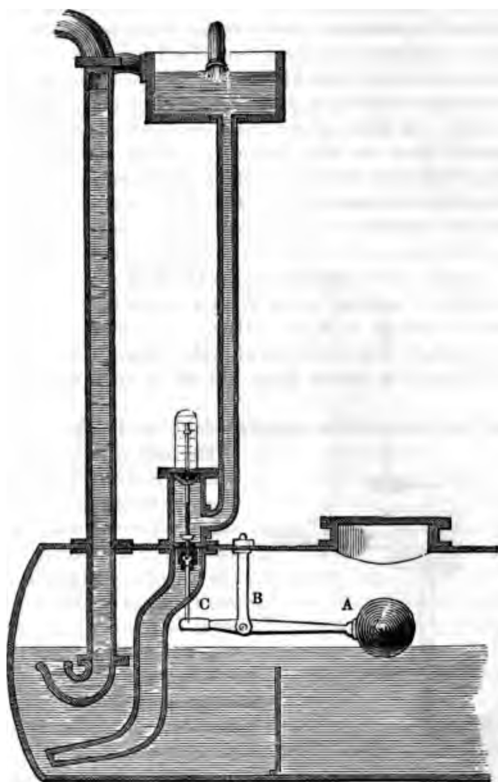


Fig. 82.

138. **Prony's float.** — The application of the above expedients requires the presence of a feeding reservoir placed above that from which the invariable vein flows. An apparatus was contrived by Prony, by which a constant level is maintained without such a feeder.

This apparatus, represented in *fig.* 83., consists of a cistern A B, filled with water, in which two empty boxes, C C, float. These are united by a bar of iron, which, descending below the bottom of the cistern, sustains under it a movable reservoir D. A plate E, attached vertically to the side of the reservoir A B, is pierced by holes of different magnitudes. A funnel, properly placed, receives

the water which flows from one or other of these openings, and conducts it by a bent pipe into the movable reservoir D.

By this arrangement, the water which flows from the fixed reservoir A B, passing into the movable reservoir D, increases the weight of the latter, which, producing a corresponding increase of the downward pressure of the floats C C, force them into the water in A B, until they displace so much of it exactly as is equal to the quantity which has been discharged into the movable reservoir D. Since, therefore, the floats occupy the same space as the water discharged, the level of the surface will be maintained invariable.

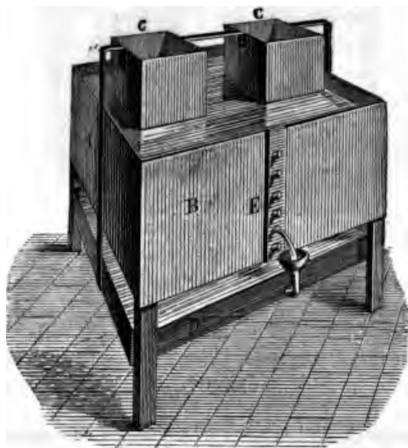


Fig. 83.

139. **Clepsydra, or water-clock.**—The ancients used the flow of water issuing from a pipe as a measurer of time. For this purpose, however, it was necessary that the discharge should be perfectly uniform, and, consequently, that the level of the water in the cistern from which the discharge pipe issues should be constant. This invariable level was obtained by a very simple expedient shown in *fig.* 84., where A is the cistern, and C the pipe from which a uniform discharge is maintained. The cistern is fed by a cock B, which discharges more water than that which issues from C, and consequently the level of the water would continually rise in the cistern; this, however, is prevented by the discharge pipe D, so that the level of the water is continually maintained at the point from which that spout issues.

If the stream issuing from the spout C be received in a tall cylindrical vessel, it is evident that the level of the surface in such a vessel will rise at a rate proportionate to the quantity of water discharged per minute from the pipe C; and since this discharge

is rendered uniform by the means above explained, the ascent of the surface of the water in the cylindrical vessel will be also uniform.

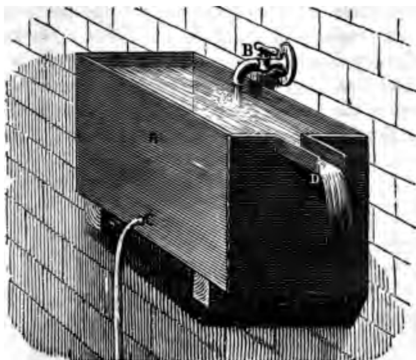


Fig. 84.

If the latter vessel, being made of glass, had a divided scale engraved upon it, each of the divisions of which would correspond to a given interval of time, an hour for example, it would serve as a chronometer, the successive hours being indicated by the coincidence of the level of the water with the successive divisions of the scale.

One of the methods of constructing such a chronometer, adopted among the ancients, is shown in *fig.* 85., where the base of the column is the reservoir into which the uniform discharge of water takes place. The two figures which appear on the base, are supported upon a float resting on the surface of the water, and rising with it. One of the figures holds a wand, which points to a divided scale upon the column, and as the figure is raised with the float, the wand points to the successive hour lines.

Another form of clepsydra is shown in *fig.* 86., where the lower discharge is rendered uniform by the maintenance of a constant level in the cistern above it.

The float A, which is raised at a uniform rate, in the manner already described, is suspended by a chain or cord coiled round an axis B, and counterpoised by a weight C; the float A being so adjusted that the counterpoise C is only capable of supporting it when A is partially sustained by the water; as A is uniformly raised, the axis B receives a uniform motion of revolution, which it imparts to the hand attached to it, which moves on the dial plate.



Fig. 85.



Fig. 86.

140. **Artesian wells.** — It has been ascertained by geologists that the crust of the globe consists of a certain series of strata composed of various mineral matters, which, in their regular and normal state, were deposited horizontally one above the other, as sand is deposited at the bottom of the sea. They have not, however, remained undisturbed in that state, but have in some places been thrust upwards, and in others have sunk downwards, so that, at present, the same strata which were originally level are rendered either concave or convex, as the case may be, towards the upper surface. Some of these strata are composed of materials through which water can easily percolate, while others are impervious to that liquid. If we suppose a stratum of the former kind to be included between two strata of the latter kind, we may imagine the possible existence of a subterranean sheet of water, prevented from rising to the surface by the impervious stratum which is above

it, and from sinking lower, by the equally impervious stratum which is below it.

Let us suppose such a triple system of strata to have the curved form represented in *fig*. 87., B and C being the impervious strata,

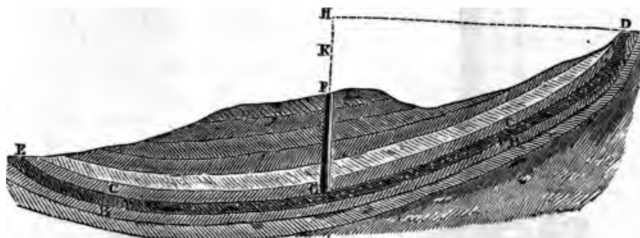


Fig. 87.

and A A that which is pervious, and which, in fact, is charged with water. Let these strata "crop out," as geologists call it, at D and E; the pervious stratum will receive at these points a constant supply of pluviose waters, and the water with which it is charged will press against its sides with a force proportionate to the difference between the levels of D, and the place where the pressure is produced.

Let us suppose now that it is desired to obtain, by means of a well, a supply of water at F. A vertical shaft is accordingly sunk at that point, which, after penetrating successively the several strata, having at length passed through C, arrives at the permeable stratum A A, which is charged with water. The water, being no longer confined, now rushes up the shaft, and if a tube were inserted in it at F, it would rise to some such level as K, between the levels of D and E, at which the permeable stratum crops out. If the tube inserted in the mouth of the shaft be removed, the water will spring up, and rise to a certain height forming a natural *jet d'eau*.

A fountain produced in this manner is called an *Artesian well*, the practice of constructing such wells having prevailed for many ages in the province of Artois, in France, and the discovery of the expedient having been assigned to that locality. It is known, however, that such wells were constructed in ages much more remote in Egypt and in the East.

Owing to the great depth to which in most cases it is necessary to sink for these wells, the shafts are made of very small transverse diameters; they are, indeed, more properly holes than shafts, their entire diameter not exceeding from 12 to 18 inches. They are bored by means of peculiar tools, by which, while the matter drawn out of them is taken up, a hollow iron cylinder is let down,

so as to line the surface of the shaft, and effectually prevent the sides from falling in. The depths to which these shafts have been driven, in some cases, is truly surprising. In the case of the well-known Artesian well on the plain of Grenelle, near Paris, the shaft is sunk to the depth of nearly 1800 feet, and the water rises with such a force that, when received in a vertical tube, it would rise 120 feet higher.

It has been observed that the quantity of water supplied by Artesian wells frequently varies with the level of the water in neighbouring reservoirs. Thus, in the case of such wells sunk in the neighbourhood of the sea, the supply is often found to vary with the rise and fall of the tide.

Such circumstances are not at all surprising, and obviously arise from the fact that, in such cases, the permeable stratum, which feeds the well, crops out at the bottom of the sea, or at the bottom of whatever lake or other reservoir it may be, whose level is observed to affect the supply.

141. The well of Grenelle is said to be capable of supplying water at the rate of about 14½ millions of gallons per day.

142. Let us suppose the possible case of a permeable stratum, which has an impervious stratum above it, but one which is not impervious below it. If a shaft be sunk from the surface to such stratum, a well will be formed, but the water will not rise in it to the surface, but only to a certain level; if it be attempted to fill such a well, by pouring water into it, the attempt will be fruitless, for whatever be the quantity of water poured in, the elevation of level which it produces will only be temporary; the increased downward pressure attending it will force the water in the permeable stratum into the stratum which is under it.

Such a well is called an *absorbing well.*

143. A curious case of the combination of two Artesian wells and an absorbing well occurs in the town of St. Denis, near Paris. In the middle of the "Place de la Poste aux Chevaux," there is a well, which was constructed in the following manner: — A shaft was first sunk, by means of which an absorbing well was found. This shaft was made of sufficient diameter to hold within it two others; the second being inserted in it by means of an iron cylinder concentric with it, the absorbing stratum was bored through, and the shaft continued to a lower stratum, which was found to be a permeable one included between two impermeable; and an Artesian well was produced which brought water to the surface.

But the operation did not stop there; a third tube being inserted within the second, the boring was continued still deeper, until another permeable stratum included between two impermeable was attained, and another Artesian well produced.

Thus three concentric tubes, one passing within the other, and leaving spaces between them, were sunk to three different depths. The innermost and deepest tube brought up water from the lowest stratum; the second, or intermediate tube, brought up water from the intermediate stratum, the water rising in the space between it and the innermost tube.

The town is supplied from these two, and the surplus waters, falling back between the outside and the intermediate tube, sink into the absorbing well.

Absorbing wells have their peculiar utility; thus, they supply convenient means of disembarrassing the surrounding neighbourhood of unhealthy waters, of draining marshes, drying up the damp foundation of buildings, and carrying away the liquid filth often produced around manufacturing establishments.

144. **Velocity of a stream at different depths.**—It has been already shown that the velocity of different parts of a stream will be different, according to their different distances from the surfaces, whose friction has a tendency to retard the motion; the principal of these surfaces being the bottom, it follows that the stratum of water in immediate contact with the bottom, flows more slowly than that which is immediately above it; and, according to what has been explained, it will be seen that each succeeding stratum in ascending flows faster than the one under it.

This gradual increase of velocity would go on until we arrived at the surface, which, at the centre of the stream, would be the most rapid, were it not that the resistance of the air in contact with the surface produces a sensible effect. Supposing, then, the air to be itself free from any independent currents, the stratum in contact with the surface of the water, having a certain adhesion to it, will be carried forward with the stream, and this portion will carry with it a part of the stratum above it, and so on. A part of the force of the stream, therefore, at the surface, being thus shared with the air, that force, and consequently the velocity of the stream, will be proportionally diminished.

It appears, therefore, that the air at the surface, as well as the solid bottom of the river, has a certain effect in retarding the current, and consequently the most rapid part of the stream will not be at the surface of the river, but at some point between the surface and the bottom.

It becomes, then, a question of some physical importance to ascertain, by direct observation, what the velocity of a stream is at different depths below the surface.

145. This has been accomplished by means of the stream gauge invented by Mr. Woltmann.

This instrument consists of a small wheel turning freely on a

is, from which five arms diverge, carrying flat vanes, which can inclined at any desired angle to the axis. This wheel revolves an axis, upon which there is a worm or endless screw G (*fig.* , where the instrument is represented in its actual magnitude).

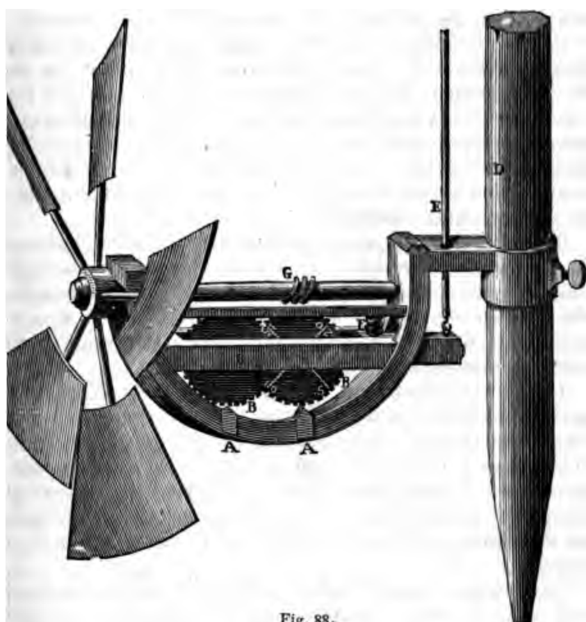


Fig. 88.

er this worm is a toothed wheel, which is capable of being put nnection with it, and which carries upon its axis a pinion, h imparts to another similar toothed wheel a much slower on. These two wheels B B turn in centres in the movable c, which plays upon a centre to the left of the frame, and is ble of being raised by the rod E, until the teeth of the left- wheel are engaged in the worm. When the rod E is not n upwards, the lever C is lowered by the reaction of the g F, the upper end of which is fixed against the framework of nstrument. When the lever C is thus pressed down, two pro- ng pieces A A enter between the teeth of the wheels B B, and their motion. The entire apparatus slides upon the iron D, to any part of which it can be fixed by a tightening screw, head of which appears in the figure.

When it is desired to ascertain the velocity of the current at any proposed height above the bottom of the river, the instrument is fixed upon the rod D at that height above its lower extremity, allowing for the portion of it which may sink into the bottom. The rod carrying the instrument is then let down until it rests on the bottom, the wheel being turned to face the current. The action of the current will soon impart a uniform motion to the vanes of the wheel. The rod E is then drawn up, and the toothed wheel B brought into connection with the worm; the moment when this takes place being noted, the instrument is allowed to act for any proposed time; say, for example, five minutes; at the expiration of which the rod E is disengaged, the wheels B B fall out of connection with the worm, and their motion is instantly stopped by the projecting pieces A A.

On drawing up the instrument, the number of revolutions made by the wheels is ascertained by marks engraved upon them for the purpose; and it will be easily understood that the proportion of the velocity of revolution imparted to the wheels B B to the velocity of the stream being known, the latter velocity will be inferred from the former.

146. By measuring the velocity of a river by this instrument at different depths, and at different distances from the banks, the mean velocity with which the water passes the transverse section at the place of observation can be ascertained; and in this way, when the superficial magnitude of the transverse section of the stream is known, the actual quantity of water which flows along the river in a given time at the place of observation can be computed.

To ascertain the magnitude of the transverse section, it will be only necessary to find the depths at given intervals, 10 feet, for example, from bank to bank. If a mean of these be taken, and multiplied by the width of the river, the product will express the area of the section; and if this area again be multiplied by the mean velocity of the stream, the actual quantity of water which flows along the bed of the river at the point of observation will be found.

Thus, for example, if the width of the river be 40 yds., and its mean depth 6 yds., the area of the section will be 240 square yds. If the mean velocity of the current be 2 yds. per second, 480 cubic yds. of water will flow along its bed per second.

A sufficient approximation to the mean velocity of a stream can be obtained without the difficult process attending the application of an instrument such as above described. It results, from an extensive series of experiments made by Dubuat, that the mean velocity has a fixed numerical relation to the superficial velocity;

and that if the latter be expressed by the numbers in the first column of the following table, the former will be expressed with sufficient approximation for all practical purposes by the corresponding numbers in the second column.

Superficial Velocity.	Mean Velocity.	Superficial Velocity.	Mean Velocity.
2	1·5	22	18·8
4	3·1	24	20·6
6	4·7	26	22·5
8	6·4	28	24·3
10	8·1	30	26·2
12	9·8	32	28·1
14	11·6	34	30·0
16	13·4	36	31·8
18	15·2	38	33·7
20	17·0	40	35·6

147. The velocity of rivers is very various, the slower class moving at less than 3 feet, and the more rapid at so much as 6 feet per second. Thus, the velocity of the Seine, at Paris, in the ordinary state of the river, varies from 2 feet to 2¼ per second; while that of the Rhone and the Rhine is 7 feet per second, and twice that speed in floods.

The quantity of water which passes over the beds of rivers in a given time is very various. In the smaller class of streams it amounts to from 300 to 350 cubic feet per second. In the smaller class of navigable rivers it amounts to from 1000 to 1200 cubic feet, and in the larger class to 14000 cubic feet, and upwards. The Seine, at Paris, under ordinary circumstances, passes between 4000 and 5000 cubic feet per second; the Garonne, at Toulouse, discharges above 5000, and the Rhone, at Lyons, more than 20000 cubic feet per second. All these numbers, however, are subject to great variations, according to the rise and fall of the streams. Thus, in times of great drought, the discharge of the Rhone, at Lyons, was only 7000 cubic feet; while, in the flood of the 12th of February, 1815, it discharged 200000 cubic feet.

148. **Resistance of liquids to solids moving through them.** — If a solid presenting a flat surface in the direction of its motion be moved through a liquid which is at rest, it will suffer a certain resistance, depending on the magnitude of such surface and the vessel in which it is moved. This resistance arises evidently from the reaction of the liquid which the solid displaces, and to which it imparts motion. Whatever moving force the liquid receives must be lost by the solid, or by whatever agent replaces the solid. It is nearly self-evident that with the same velocity the resistance will be proportional to the magnitude of the surface; for it is clear that a surface which measures two square

feet will drive a column of water twice as great as that which would be driven by a surface measuring one square foot. The resistance, therefore, other things being the same, to a flat surface moved against a liquid, is proportional to the area of such surface.

149. **A flat surface encounters a resistance which is as the square of the velocity.** — It is evident also that if the same surface be moved with different velocities, it will encounter different resistances. The greater the velocity with which it is propelled, the greater will be the moving force it will impart to the liquid, and consequently the greater will be the resistance it encounters. If the surface be moved with a double velocity, the liquid which it drives before it will also be moved with a double velocity, and will consequently have a double momentum or moving force; but when the surface is moved with a double velocity, it advances through a double space in the same time, and consequently displaces a double quantity of liquid. Now, since this double quantity of liquid is moved with a double velocity, it must have a four-fold momentum, since the momentum is increased in a two-fold proportion in consequence of the double velocity, and again in a two-fold proportion in consequence of the double quantity which is displaced. The moving force, therefore, which is communicated to the liquid by the solid will be four-fold when the velocity is doubled. Now, since this moving force is the measure of the resistance, it follows that when a flat surface of a given area is moved through a liquid, the resistance which it encounters will be augmented, not in the simple ratio of the velocity, but as its square. Thus, a two-fold velocity will give a four-fold resistance; a three-fold velocity a nine-fold resistance; and so on.

150. **Absolute resistance.** — It may be concluded, therefore, in general, that when a solid having a flat surface is moved through a liquid, the resistance encountered by such surface will be proportional to the magnitude of the surface multiplied by the square of its velocity. Such being the law which governs the variation of the resistance, we shall know the total amount of such resistance in all cases, provided its amount be known for any one surface and any one velocity. Now, it is proved that a square foot of surface moved with the velocity which a body would acquire in falling through 193 inches would suffer a resistance equal to the weight of a column of water of that height, and having a square foot for its base.

If a square foot of surface, then, be moved with any other velocity, greater or less, the resistance can be found by increasing or diminishing this resistance in the ratio of the square of the

velocity; and if a surface greater or less than a square foot be so moved, the resistance due to such increase or diminution will be found by increasing or diminishing the resistance encountered by a square foot in the same proportion.

151. **Force upon a surface at rest.** — If a liquid strike the flat surface of a solid at rest with a certain velocity, it will exert upon such surface a force just double the resistance which the same surface would encounter if it moved in the liquid with the same velocity, the liquid being at rest; that is to say, the force exerted on the surface by the liquid would be equal to the weight of a column of the liquid whose base would be equal to the surface, and whose height would be double the height through which a body would fall freely in order to acquire the velocity with which the liquid strikes the surface.

152. **Resistance when oblique.** — If the surface which is moved against a liquid, or upon which a liquid in motion acts, be not at right angles to the motion, then it will be necessary to resolve the motion into two, by the principle of the composition of forces, one of which shall be perpendicular to the surface, and the other parallel to it. The latter can have no effect, whether the surface strike the liquid, or the liquid strike the surface; and that element of the force which is perpendicular to the surface is subject to all the conditions which have been just explained.

153. **Form of least resistance.** — The effect produced upon the resistance offered to a body moving through a liquid by the obliquity of the different parts of the surface of such a body to the direction of the motion forms an important element in the solution of the problem for determining, under different conditions, the shape of the solid moved. A problem which has attained great celebrity in the history of mathematics, is one in which it was required to determine the form which should be given to a determinate mass of solid matter, so that it might move through a liquid with the least possible resistance. The form thus determined is known in geometry as the solid of least resistance.

154. **Naval architecture.**—Nearly similar conditions attend the solution of all the problems which are presented in naval architecture. It is this principle which causes the length of the vessel to be presented in the direction of the motion, and which determines the shape of the prow under the various conditions to which different classes of vessels are exposed. The boats which ply on rivers, or other sheets of water not liable to much agitation, nor intended to carry considerable freight, are so constructed that the part of the bottom immersed moves against the liquid at an extremely oblique angle.

155. **Form of fishes.**—It has been often mentioned, as an instance of the felicitous accordance of the works of nature with the principles of science, that the form given by mathematicians as the solid of least resistance accords exactly with the forms of the bodies of fishes. This, however, is not strictly the case, and if it were, so far from being an instance of skill and design in the works of nature, would manifest a certain degree of imperfection.

The solid contemplated in the celebrated problem adverted to, has no other function to discharge except to oppose the resistance of the fluid, and the question is one of a purely abstract nature, viz., what shape shall be given to a body, so that, while its volume and surface continue to be of the same magnitude, it may encounter the least possible resistance in moving through a fluid? It must be apparent that many conditions must enter into the construction of an animal, corresponding to its various properties and functions, independently of those in virtue of which it employs itself to cleave the water.

156. The discovery of verifications of the principles of physics in the works of nature is in general so seductive that writers are sometimes tempted to overlook the inevitable causes of discrepancy in their eagerness to seize upon analogies of this kind. Without, however, seeking in natural objects the exact solution of a mathematical problem, which is unencumbered by various conditions which the Author of Nature has designed to fulfil, innumerable examples may be produced giving striking manifestation of design. Thus, all animals to whose existence or enjoyment a power of easy and rapid motion through fluids is necessary have been created with a form which, having a due regard to their other functions, is, upon the whole, the best qualified for this end. Birds, and especially those of rapid flight, are examples of this. The neck and breast tapering from before, and increasing by slight degrees towards the thicker part of the body, causes them to encounter the air with a degree of obliquity considerably diminishing the resistance, slight as it is, which this attenuated fluid opposes to their flight. But these conditions are, as might be expected, presented in a much more striking point of view in the form of fishes, and all the species which inhabit the deep.

157. **Use of the rudder.**—When a liquid strikes upon a solid surface in an oblique direction, the force which it exerts is immediately resolved, by the principle of the resolution of force explained in "Mechanics," Book II. Chap. I., into two forces, one of which is perpendicular, and the other parallel to the surface upon which the water strikes. The latter evidently can produce no effect on the surface, since it would merely cause the water to glide along it without exercising any pressure upon it. The

component which is perpendicular to the surface is, therefore, the only part of the force which is, in this case, effective.

When a vessel is impelled through still water by a force directed from its stern to its stem, it will necessarily move in the exact direction of its keel. It is often necessary, however, to change the direction of its motion; and this is accomplished by the expedient called the rudder, which is a large flat board (*fig.* 89.),

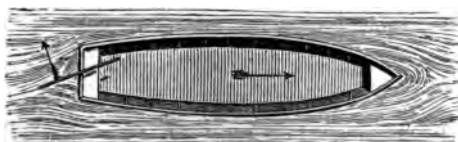


Fig. 89.

hinged upon a vertical edge forming the extremity of the keel. The rudder, therefore, turns like a door upon its hinges, right and left, so that it can be directed nearly at right angles to the keel on the one side or on the other. In the smaller class of boats it is moved by a long lever attached to the upper extremity of its axis, and which is carried over the deck near the stern of the boat. In larger vessels, however, it is turned by means of a wheel movable round a horizontal axis, having handles projecting from its edges by which the helmsman works it. A rope, which passes round the axis of this wheel, being carried under the upper deck, is attached to the lever of the rudder which it moves.

When the rudder is placed in such an oblique direction as that shown in *fig.* 89., the action of the water upon it, being perpendicular to its surface, as indicated by the arrow, has a tendency to turn the stern of the vessel to the left of the helmsman, and therefore to change the course of the vessel towards his right. If the rudder be inclined to the other direction, a contrary change in the motion of the vessel will be produced.

It is evident that, by holding the rudder continuously in the same inclined position, the vessel may be made to reverse its direction, or even to move in a circle.

This, however, is upon the supposition that the force which impels the vessel is always in the direction of its keel. The manner in which the force of the wind, acting on the sails, even when it is not in the direction of the keel, produces this effect, has been already explained in "Mechanics," (175.).

158. **Propulsion of vessels by paddle-wheels.** — The power of steam has been applied to the propulsion of vessels, either by paddle-wheels or by submerged screw propellers.

Paddle-wheels are attached to a horizontal shaft which passes across the vessel, having cranks formed at or near its centre, which receive motion from steam-engines erected in the vessel itself; the wheels, being fixed upon the ends of the shaft, revolve with it. These wheels consist of a certain number of straight arms which diverge from their axes, to the ends of which flat boards, called paddle-boards, are attached, the surfaces of which are at right angles to the plane of the wheel, and their edges directed to its centre (*fig.* 90.).

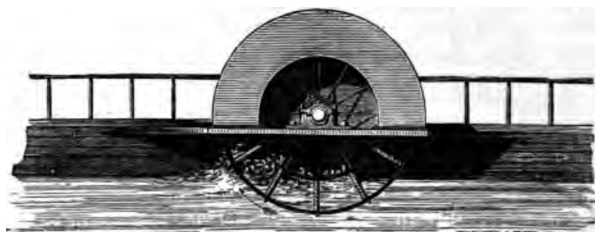


Fig. 90.

The lower parts of the wheels being immersed, the water, when they are made to revolve, is driven back by the paddle-boards, upon which the same action is produced as if the water struck the boards, the latter being at rest, with the same velocity as that with which the boards strike the water. The effect of such a force, when the paddle-board is vertical, would evidently be to propel the board, and with it the vessel, in the direction contrary to that in which the board moves. If the board be not vertical, however, the reaction of the water will be resolved into two components, one of which will be at right angles to the board, and therefore oblique to the horizontal line. This component will be again resolved into two, one of which is horizontal and the other vertical. The latter will evidently have no propelling effect, the former alone being effective.

It will be evident, upon inspecting the figure, that one paddle-board only of those immersed in the water, at any given moment, can be vertical, and that one alone therefore will be completely effective. The others, which, entering the water, are approaching the vertical position, or, leaving the water, are departing from it, being more and more oblique to the horizontal direction the more they are removed from their lowest position, will be less and less effective for propulsion. If the wheel were immersed to its axle, the boards would not only be ineffective for propulsion on entering and leaving the water, but would even produce a certain amount

of resistance. If, in fine, the wheel were immersed below its axis, the paddle-boards immersed above the axis would drive the vessel backward with exactly the same force as that with which the corresponding paddles below the axis would impel it forward. Since these two reactions therefore neutralise each other, all the moving power expended in producing them is absolutely lost.

It is accordingly found in practice that paddle-wheels of a given diameter act with the greatest effect when their immersion does not exceed the depth of the lowest paddle-board, and that, other things being the same, the efficiency within practical limits will increase with the diameter of the wheel.

But this invariable degree of immersion can never be maintained, except when the vessel moves in water absolutely smooth, maintaining herself in the vertical position. If she incline even momentarily to either one side or the other, one paddle-wheel will be too much and the other too little immersed. In the vicissitudes of sea navigation such smoothness of the water only occurs in rare and exceptional cases. In general the vessel ploughs the waves, and is subject to more or less pitching and rolling, the result of which is a great and continual variation of the immersion of the paddle-wheels, and a corresponding inefficiency of their action.

In river boats, on the contrary, paddle-wheels act to the greatest possible advantage, the water being so invariably smooth that they have always the immersion which gives them the greatest possible efficiency. I have accordingly found the best and largest class of steam-boats plying on the Hudson, moving at the rate of from 18 to 20 miles an hour.

159. **Screw propellers.**—These causes of inefficiency and waste of the propelling power have of late years turned the attention of steam-boat projectors and engineers to the discovery of some form of subaqueous propeller which would be exempt from such disadvantages, and the result has been the successful application of that particular form of submerged propeller called the *screw*.

To understand the manner in which this propeller acts, let us imagine that a large screw were extended along the vessel under the keel. If the water in which this screw is submerged were solid, it is evident that, by turning the screw round in one direction or the other, it would move through the water, carrying the vessel with it, the space through which it would move in each revolution being equal to the interval between two contiguous threads of the screw. In fact, in such a case the water would play the part of a fixed nut in which the screw would turn; and it has been shown in "Mechanics," (484.), that in such case the screw would move forward or backward through the nut,

according to the direction in which it is turned, in the manner here stated.

But the water, though far from being fixed in its position like a solid nut, offers, nevertheless, a certain resistance to the screw. If it yielded to the screw without reaction, the water would be moved backwards by the screw exactly as a movable nut is when the screw is fixed. But the water having considerable inertia, though it yields to the screw, reacts upon it, and such reaction produces a corresponding impulsion in the vessel.

The screw is usually formed by constructing an helical vane, turning spirally round an axle, which passes vertically over, and parallel to, the keel, and is placed immediately in front of the rudder.

It is evident from what has been stated that the action of this

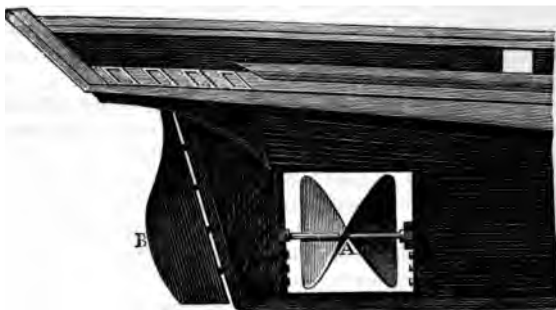


Fig. 91.

propeller will be the same, whatever be the position of the vessel, or whatever its degree of immersion. Its advantages, therefore, over paddle-wheels for sea navigation, are numerous and important. To render paddle-wheels efficient the vessel must be kept nearly upright. This is often impracticable when sails are used with a side wind. With the screw, however, the vessel may take any attitude in the water which is natural to a sailing-vessel.

When a steam-vessel starts on a long voyage, it is heavily laden with coals, and consequently deeply immersed. At the end of the voyage, the coals being for the most part consumed, it is much less deeply immersed. If, therefore, at starting the depth of immersion of the wheels be that which gives them greatest efficiency, they would be nearly or altogether raised out of the water on arriving; and if they were so regulated as to have the proper immersion on arriving, they would be much too deeply immersed at starting. In no case, therefore, could they have the best

immersion during the whole or even a considerable part of the voyage.

From this defect the screw propeller is completely exempt.

160. **Hydraulic machines for raising water.** — The various processes by which liquids, and more especially water, are elevated from a lower to a higher level occupy an important place in the application of physical principles to the industrial arts. Sometimes it is required to drain the foundations of structures, such as docks, harbours, locks, &c., which are in process of construction. Sometimes it is required to clear deep excavations, such as the shafts and workings of mines, &c., the tunnels for railways and canals, of the water by which they are inundated, so as to enable the workmen to enter them. Sometimes it is required to raise water through much more limited heights, as when that of a river is distributed over the ground along its banks for irrigation. Sometimes water is required to be raised for domestic use, and in industrial establishments, that, as well as other liquids, is often elevated from floor to floor to be then distributed.

A vast number of machines have been invented for these purposes, which vary in their form, magnitude, and power, according to the circumstances under which they are applied. We shall here explain some of the most important of these, the structure and operation of which involve no other physical principles than the mechanical properties of liquids. Such as depend upon the properties of elastic fluids, among which are comprised most forms of pumps, will be explained in a subsequent part of this volume.

161. **Method of estimating the useful effect.** — The power exerted by any machine applied to this purpose is estimated and measured by the weight of water raised, combined with the height through which it is elevated.

If we suppose W to express the number of pounds weight of water raised, and F the number of feet through which it has been elevated, then the power, or useful effect, as it is called, produced by the machine will be expressed by the product of the numbers W and F. Thus, if W be 100 and F 10, that is, if 100 lbs. of water be raised 10 feet, the useful effect produced by the machine will be expressed by 1000; inasmuch as 100 lbs. raised 10 feet is equivalent to 1000 lbs. raised 1 foot.

If, then, we suppose E to express the useful effect, or, what is the same, the equivalent number of lbs. raised 1 foot, we shall have

$$E = W \times F.$$

162. **Power lost upon the machinery.** — If it were possible to construct a machine so perfect, as to transmit the whole effect of the power applied to it to the water to be raised, then the power

so applied would be equal to E. But this is impracticable, because between the power and the water there are a great number of resistances which severally absorb more or less of the power. Among these the principal are —

1°. The friction of the moving parts of the machine applied to elevate the water.

2°. The friction of the water with the various solid surfaces in contact with which it moves.

3°. The resistances produced and force lost by sudden changes of direction of the motion, either of the solid parts of the machine, or of the water.

4°. The resistances produced and force lost by sudden changes of velocity, either of the machine or the water, or both.

5°. The momentum which the water may retain after its elevation has been completed, which momentum, while it absorbs more or less of the moving power, is unnecessary for the purposes to which that power is applied.

All these things must be kept in view by those who would apply machinery to the elevation of water.

163. **Relation between the power and useful effect.** — If we express by P the whole amount of power applied to the machine in an equivalent number of pounds weight raised 1 foot, and by L the part of this power which is absorbed by the various resistances above mentioned, it is evident that L will be the number by which P exceeds E, so that we shall have

$$P - E = L;$$

or, what is the same,

$$P = E + L;$$

that is to say, the power applied to the machine must be equal to the useful effect produced together with the resistances opposed to it by the machine.

164. **Method of raising water from wells.** — As water is one of the most universal necessaries of life, and abundant as it is in nature, is not always found in the localities where circumstances oblige us to fix our habitations, expedients by which it can be obtained in sufficient quantity, and of the necessary purity, have been among the earliest mechanical and physical inventions in every country. Natural springs showed that sources of water existed in the lower strata of the earth. This suggested the process of well-sinking or boring for water. But the water when thus found rarely rises to the surface spontaneously. It does so in those deep springs called Artesian wells; but in all ordinary cases where a shaft has been sunk deep enough to find water, the water collects in the bottom of the shaft, and never rises above a certain level.

Expedients are therefore necessary in all such cases to raise it to the surface.

165. **By lever.** — The first and rudest of these contrivances is to let down a bucket by means of a rope, and thus to draw up one bucket-full after another. The rope by which the bucket is elevated, when the well is not very deep, is sometimes attached to the long arm of a lever (*fig.* 92.), the shorter arm being pulled

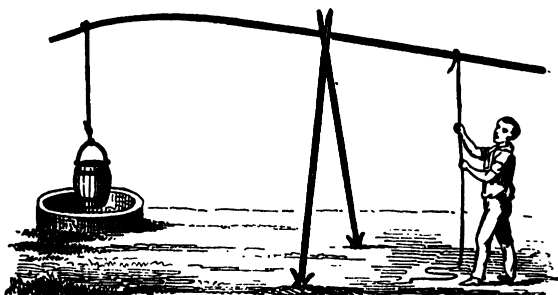


Fig. 92.

down when the bucket is drawn up full. This is perhaps the rudest and most inartificial of all contrivances for the elevation of the water.

A pulley established over the mouth of the well is a degree more efficient. The bucket, being let down and dipped in the water, is drawn up by pulling the rope.

In this case the labour is expended not only in raising the weight of the water and of the bucket which contains it, but also that of the rope, which, if the well be deep, is not inconsiderable. Besides this a certain force must be exerted to bend the rope continually over the groove of the pulley, and to overcome the friction of the pulley itself in moving upon its axle.

166. **By windlass.** — A windlass established over the mouth of the well (*fig.* 93.) is more efficient than these rude expedients. In this case the bucket is raised by turning the winch of the windlass, so that the rope is gradually wound upon its axle. The power has still to raise the weight of the rope, to produce its

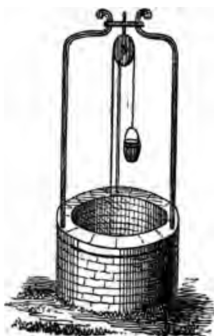


Fig. 93.

flexure on the axle, and to overcome the friction of the axle of the windlass in its bearings.

In the contrivance of mechanical agents, the first object is always to remove as much as possible all sources by which the moving power is absorbed upon useless objects. In the present case the only useful exertion of the moving force is that which is engaged in raising the water. The useless parts of the force expended, are, *first*, that absorbed by the weight of the bucket; *secondly*, that absorbed by the weight of the rope; *thirdly*, that absorbed in bending the rope over the groove of the pulley, or the curvature of the axle; *fourthly*, that which is expended on the friction of the axle in its bearings; *fifthly*, that which is expended in drawing the bucket aside when it has been elevated, and discharging the water from it into the vessel or reservoir destined to receive it; and, *sixthly*, that which is expended in letting down the bucket into the well to be refilled.

Now when all these sources of waste of power are considered and estimated, and their aggregate amount determined, it will be apparent that they greatly exceed the force expended upon the mere elevation of the water.


Fig. 94.

167. **By fixed pulley.** — A part of the loss of power arising from these causes is sometimes removed by the simple expedient of attaching two buckets to the extremities of the rope which passes over the pulley (*fig.* 94.) established above the well. By these means, while the full bucket is drawn up the empty one descends, and by its weight and that of the rope which descends with it, the weight of the full bucket and the rope which ascends with it is balanced, so that the power has only to act against the weight of the water, the friction, and the resistance to flexure presented by the rope.

168. **By horse shaft.** — Animal power may be applied to this method of raising water by such an arrangement as is represented in *fig.* 95. This is the method generally used in France by the market gardeners, in the environs of large towns, to raise water for irrigation. Two pulleys are established side by side, over the well, at such a distance asunder that two buckets or barrels suspended from them may pass each other as one ascends and the other descends, without mutual collision or obstruction. The rope supporting one bucket, after passing over one of these pulleys,

is carried two or three times round a large vertical drum erected near the well, and then, passing over the other pulley, is let down into the well with the other bucket attached to it.

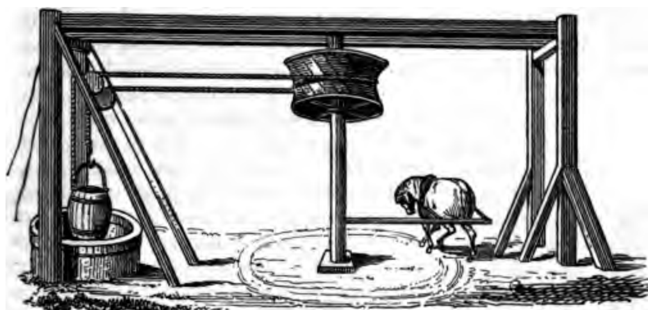


Fig. 95.

The semicircular handles to which the rope is attached, are connected with the barrels, not at the edge of the mouth, but at two points in their sides, a little above their middle point, so that when filled they will maintain themselves steadily in the vertical position, but when empty they will easily be turned upon their sides by mere contact with the surface of the water, so as to fill themselves, when let down empty.

A horse or ox yoked to a lever of considerable length, projecting from the vertical shaft, turns it, and with it the drum, and continues to go round in the same direction, until one barrel is raised to the mouth of the well and the other plunged in the water below and filled, the contents of this barrel being discharged into a reservoir or vessel destined to receive it. The animal is then yoked in the other direction, and again travels round until the other barrel is raised, and that which was just discharged let down.

It is evident that in this and all similar arrangements the weight of the rope on the whole balances itself; for although it preponderates against the power when the full barrel begins to ascend, the ascending part of the rope being then longer than the descending, this preponderance gradually decreases until the ascending meets the descending barrel. At this point, the ascending and descending parts of the rope, being equal, balance each other, and after this the descending part, preponderating, aids the power just as much as the ascending part previously opposed it. There is, therefore, so far as relates to the weight of the rope, a perfect compensation.

The same apparatus is much used in France, in raising stone

through vertical shafts from subterranean quarries, and other mining operations.

169. **Lifting pump.**—If, instead of a rope and bucket, a pipe or tube be let down into the well, and in this pipe a piston be provided, having a valve in it opening upwards, this piston being worked in the usual manner upwards and downwards, the water would be lifted in the pipe. Such an apparatus is called a lifting pump, and is represented in *fig.* 96. W is the water, *c d* the piston, *u* the valve in it which opens upwards. When the piston is moved downwards, this valve opens, and the water passes through it. When the piston is moved upwards, the column of water is pushed up, and the valve is kept closed by the pressure of the water upon it. A valve *x* is placed at C D in a fixed position, through which the column of water passes when the piston rises, and and which prevents the return of such water downwards, the valve being kept closed by the weight of the water above it. The column of water driven upwards by the piston is pushed to any required height, through the pipe E F. In such an apparatus, the moving power must be equal to the weight of the water raised, together with the weight of the pump-rod and frame by which the piston is worked, as well as the friction of the moving parts.

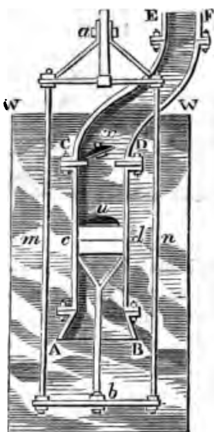


Fig. 96.

170. **Double lifting pump worked by weight.**—A very ingenious form of pump which, though differing altogether in appearance from the lifting pump, acts nevertheless upon precisely the same principle, is shown in *fig.* 97. It has the advantage of being nearly free from friction, and of being capable of being worked by the weight of an animal walking up an inclined plane, which is the most advantageous manner in which animal power can be applied.

Let D C be a wooden tube of any shape, round or square, which descends to a depth in the well or reservoir equal to the height above the surface of the reservoir to which the water is required to be raised. Thus if D O be the height to which the water is to be raised above the level of the well, then the depth O C must be at least equal to D O. L M is a heavy beam or plunger, suspended from a chain, and capable of descending by its own weight in water, and passing water-tight through the collar F E. A valve, *v*,

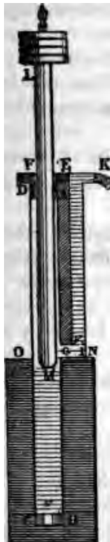
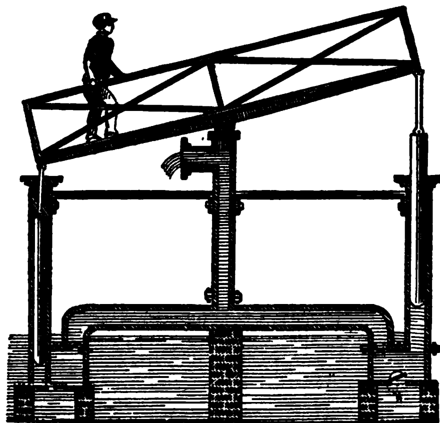


Fig. 97.

covers an opening placed at the bottom of the tube. By the hydrostatic pressure the water will enter the valve *v*, and fill the barrel to the level O G of the water in the cistern. G I is a short tube proceeding from the side of the barrel, at the surface of the water, and communicating with the vertical tube E N by a valve I, which opens upwards. K is the spout of discharge. The plunger L M hangs loosely in the tube, so that it moves upwards and downwards perfectly free from friction, except that of the collar F E, where it is properly lubricated. When this plunger is allowed to descend by its weight into the water which fills the lower part of the tube, the valve *v* is closed, and the water displaced by the plunger is forced through the valve I into the tube E N. When the plunger is raised the valve I is closed, and the water thus forced into the tube E N cannot return. The water from the cistern then flows through the valve *v*, and rises in the tube to the level G. The next descent of the piston propels more water into the tube E N, and this is continued so long as the piston is worked.

The manner in which such an apparatus is worked by the weight of a man, or any animal, is represented in *fig*. 98. Two pumps are used, such as that just described, and when the plunger descends in one it rises in the


Fig. 98.

other. The two pumps communicate with one vertical pipe, which therefore receives a continual supply of water; for while the action of one pump is suspended, the other is in progress. A man walks from one end of an inclined plane to the other, and by his weight upon one side or the other of the fulcrum causes the plungers alternately to rise and fall.

171. **Valves.** — Valves are of such constant use in all forms of pump, that it will be useful here briefly to explain their principal varieties.

A valve in general is a contrivance by which water or other fluid flowing through a tube or aperture is allowed free passage in one direction, but is stopped in the other. Its structure is such that while the pressure of the fluid on one side has a tendency to close it, the pressure on the other side has a tendency to open it.

As in all forms of pump the water is required to be moved upwards, all the valves necessarily open upwards and close downwards.

There are several varieties of form.

172. **Clack valves.** — The clack valve is like the lid of a box (*fig.* 99.). It opens upwards, playing upon a hinge, and when the water presses it downwards it is closed.



Fig. 99.

The single clack valve is the most simple example of the class. It is usually constructed by attaching to a plate of metal larger than the aperture which the valve is intended to stop, a piece of leather, and to the under side of this leather another piece of metal smaller than the aperture. The leather extending on one side beyond the larger metallic plate, and being flexible, forms the hinge on which the valve plays. Such a valve is usually closed by its own weight, and opened by the pressure of the fluid which passes through it. It is also held closed more firmly by the pressure of the fluid whose return it is intended to obstruct.

The extent to which such a valve should be capable of opening, ought to be such that the aperture produced by it shall be equal to the aperture which it stops. This will be effected if the angle through which it rises be about 30°.



Fig. 100.

A double clack consists of two semicircular plates, having the hinges on the diameters of the semicircles, as represented in *fig.* 100.

Of the valves which are opened by a motion perpendicular to their seat, the most simple is a flat metallic plate, made larger

than the orifice which it is intended to stop, and ground so as to rest in water-tight contact with the surface surrounding the aperture. Such a valve is usually guided in its perpendicular motion by a spindle passing through its centre, and sliding in holes made in cross bars extending above and below the seat of the valve.

173. **Conical valves.** — The conical valves, usually called spindle-valves (*fig.* 101.), are the most common of this class. The best angle to be given to the conical seat is found in practice to be 45°. With a less inclination the valve has a tendency to be fastened in its seat, and a greater inclination would cause the top of the valve to occupy unnecessary space in the valve-box. The area, or transverse section of the valve-box, should be rather more than double the magnitude of the upper surface of the valve, and the play of the valve should be such as to allow it to rise from its seat to a height not less than one fourth of the diameter of its upper surface.



Fig. 101.

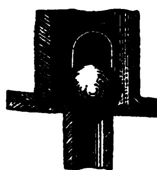


Fig. 102.

174. **Ball valves.** — The valves coming under this class are sometimes formed as spheres or hemispheres (*fig.* 102.) resting in a conical seat, and in such cases they are generally closed by their own weight, and opened by the pressure of the fluid which passes through them.

175. **Chain pump.** — When the height through which water has to be elevated is not considerable, as in the cases in which the foundations of docks and other similar structures are to be drained, one of the most convenient forms of hydraulic machine is the chain pump, represented in *fig.* 103.

This machine consists of a cylinder, the lower part of which is immersed in a well or reservoir, and the upper part enters the bottom of a cistern into which the water is to be raised. An endless chain is carried round the wheel at the top, and is furnished at equal distances with pistons or movable bottoms which fit water-tight in the cylinder. As these successively enter the cylinder, they carry the water up before them, which is discharged into the cistern at the mouth of the cylinder above. The moving power is usually applied by a winch or otherwise to the wheel. The cylinder may be placed in an inclined position, as shown in *fig.* 104., in which it works to more advantage than when vertical. The effect is greatest when the distance between the pistons is equal to their diameters.

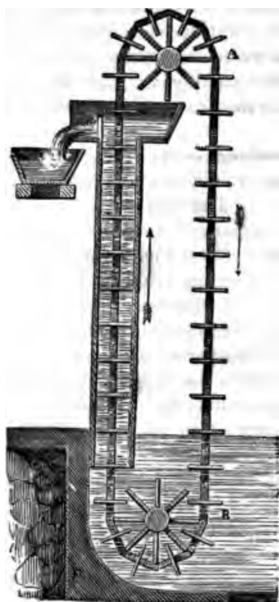


Fig. 103.

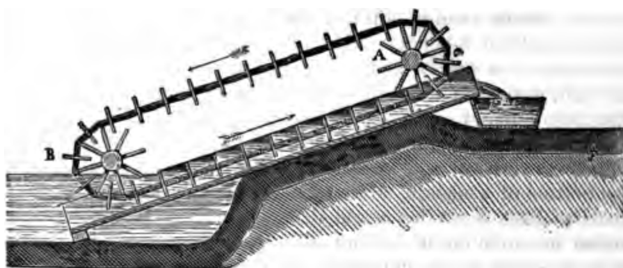


Fig. 104.

176. **Noria.**—This is a modification of the chain pump, in which the discs are replaced by buckets which have their mouths upwards in ascending, and downwards in descending, the cylinders surrounding the disc being dispensed with. The buckets rise filled with water, which they discharge into a reservoir at the moment that they are turned over the upper wheel.

This machine, however, is not exclusively employed for the elevation of water. In various factories it is used to raise solid bodies in the state of powder from one part of the building to another. Thus, for example, in flour mills, it is used to convey the flour as it is discharged from the stones to those parts of the building in which the bran is separated from it.

177. *Dredging machines* are constructed upon this principle, the endless chain being inclined, as in *fig.* 104. The lower wheel is let down to the bottom of the river; and the upper wheel being driven by a steam-engine, the buckets, in passing under the lower wheel, are drawn with their mouths forward against the bottom, and become filled with gravel and mud, which they bring up and discharge in passing over the upper wheel.

178. **Archimedes' screw.** — The hydraulic instrument called, after its inventor, the screw of Archimedes, has recently been invested with more than common interest by its successful application to the propulsion of steam-vessels. This machine was invented by Archimedes in Egypt, to aid the inhabitants in clearing the land from the periodical overflowings of the Nile. It was also used as a pump, to clear water from the holds of vessels; and Athenæus states that the name of Archimedes was held in great veneration by seamen on this account.

The instrument varies in form, according to the manner and purposes of its application; but its principle may be rendered intelligible as follows: —

Suppose a metal tube bent into the form of a corkscrew, as represented in *fig.* 105. Let it be placed in an inclined position, so that the mouth A, at the lower end, shall be in the highest position it can have. If a small metal ball be let into the mouth A, it will fall down the curved part till it arrives at B. This point B is evidently so situated that the ball cannot leave it either on the one side or on the other without ascending; consequently, when the ball arrives there, after a few oscillations, it will remain at rest. If the screw be now turned without changing its inclination or direction, so that the mouth A, instead of being at the highest position, as represented in *fig.* 105., shall be brought to its lowest position, as represented in *fig.* 106., the point B during such motion of the screw will ascend, and assume the highest position which it can have, as represented in *fig.* 106.

Now, suppose the ball for a moment to be attached to the tube so as to be incapable of moving in it. When the screw has been turned to the position represented in *fig.* 106., the ball B would be at the highest point of the body of the tube, and consequently would be raised from the point *b*, which it occupied before the

screw was turned, to the point B, which it now occupies. If the ball then be detached from the tube, supposing it to be a little short of the summit, it will fall down that part of the tube from B to C, and, arriving at C, it will be again at a point of the tube where

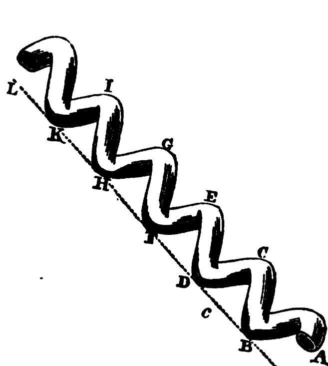


Fig. 105.

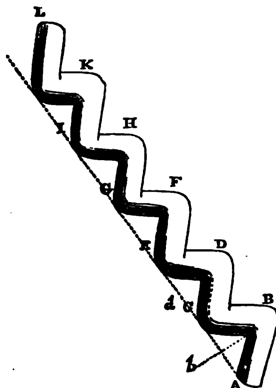


Fig. 106.

it will have an ascent at either side of it, and it will consequently come to rest.

If the ball be again supposed to be attached to the tube here, and the tube be again turned half round, so as to give to it once more the position represented in *fig*. 105., the ball will be at C, having been raised from *c* to C in this half turn. If, then, the ball be detached at C, supposing it to be a little beyond the summit, it will fall down the tube from C to D, when it will again come to rest, because it will have an ascent at either side of it.

Thus, in a complete turn of the screw the ball would be carried from B to D (*fig*. 105.); in the second turn of the screw it may be shown that it would be carried from D to F; in the third from F to H, and so on; until at length the ball would be discharged from the upper end of the tube at L. But if we do not suppose the ball to be successively attached to the interior of the tube, this motion from B to L, instead of being effected by intervals, will be made continuously; the process, however, remaining the same.

All that has been said of the ball in the tube would be equally true if a quantity of liquid were contained in it. Therefore, if the extremity of the screw were immersed in a well or reservoir, as shown in *fig*. 107., so that the water by its weight or pressure would be continually forced into the extremity of the tube, it would be gradually carried along the spiral by turning the

screw, until it would attain any height to which the screw might extend.

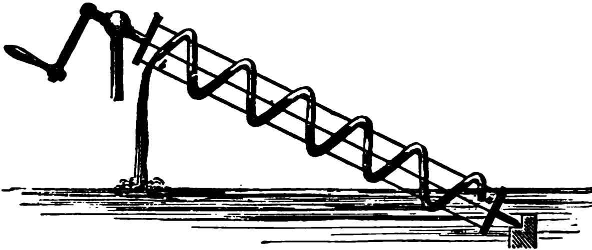


Fig. 107.

In practice, the spiral through which the water is carried is not in the form of a tube, but has the character represented in section in *figs.* 108, 109.

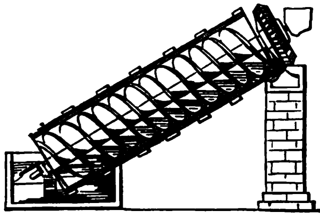


Fig. 108.

As applied to the propulsion of steam-vessels, the screw is horizontal, and exercises its power, not by raising the water, but by driving it backwards: the reaction of the water thus driven gives propulsion to the vessel.

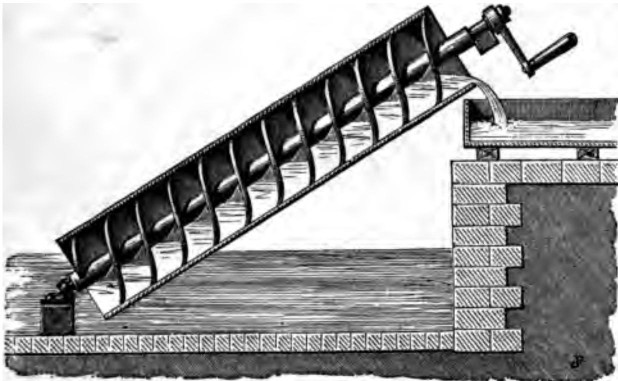


Fig. 109.

179. **The Dutch screw.** — This contrivance differs little from the screw of Archimedes. The spiral blade, instead of being attached to the cylinder, is attached to a straight shaft which runs along the axis of the screw, and is surrounded by a thick cylinder in which it turns, passing closely to its surface without touching it. It raises the water upon the same principle as the screw of Archimedes, subject to some loss of power, by leakage between the spiral blade and the fixed cylinder.

Machines of this kind are much used in Holland for the drainage of the low grounds.

180. **Paddle-wheel.** — When the height to which water is required to be raised is very inconsiderable, a form of wheel

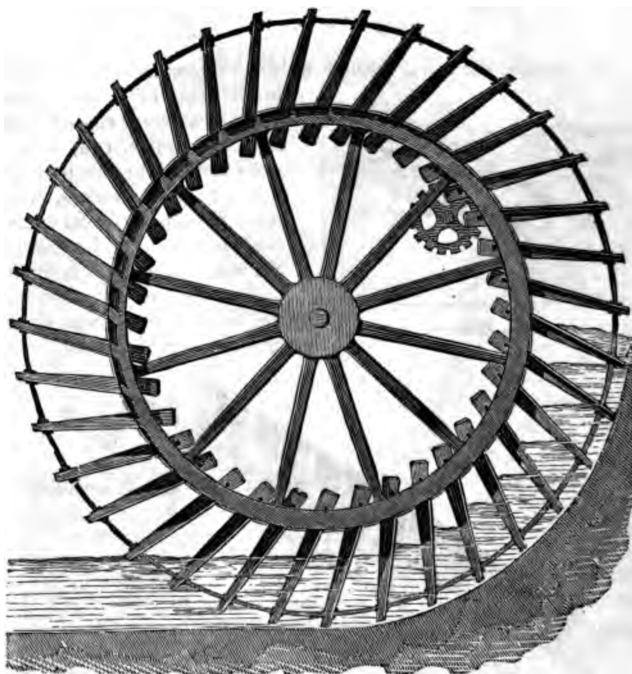


Fig. 110.

resembling the paddle-wheel of a steam-boat is applied in the manner represented in *fig.* 110. The lower paddles are immersed

in the water to be raised, and the middle ones are at the level A, to which it is to be elevated. The water is confined laterally by vertical surfaces, which form with the surface shown in the figure a sort of curved canal, corresponding in its transverse section with the form of the paddle-boards; its magnitude and position being such that these boards move through it with their edges close to the surfaces, without touching them. A wheel of this form has been erected at St. Ouen, near Paris, to raise the water of the Seine for the supply of the railway station. *Fig.* 110. represents it upon the scale of an inch to 12 feet.

181. **The lifting wheel.**—This is an hydraulic apparatus, consisting of a wheel surrounded by buckets, as shown in *fig.* 111

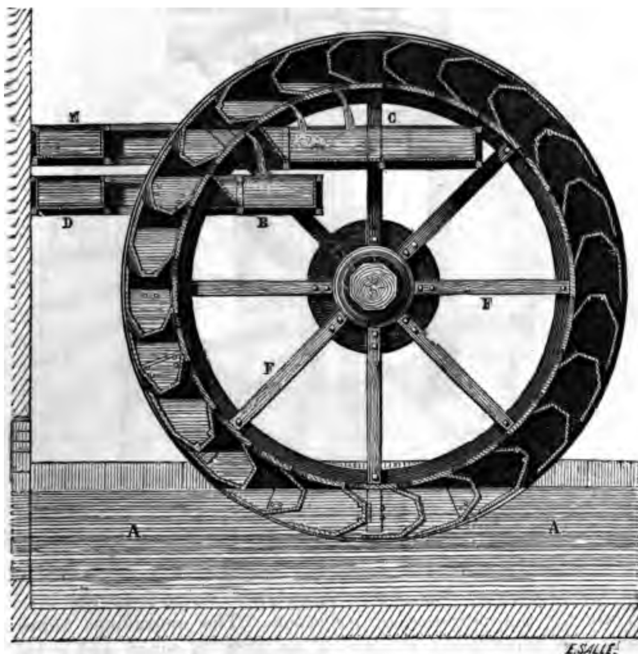


Fig. 111.

The lowest part is immersed in the reservoir A A, from which the water is to be elevated; the buckets are filled in passing through it, and they carry up the water, as shown in the figure, and discharge it near the top of the wheel into spouts B D and C E

which lead to the upper reservoir. The circumference of the wheel is connected with the centre by arms F F, and the centre is fixed upon a shaft, to which motion is imparted by a steam-engine or other moving power by means of a shaft G and toothed wheels, as shown in the end view of the apparatus given in *fig.* 112.

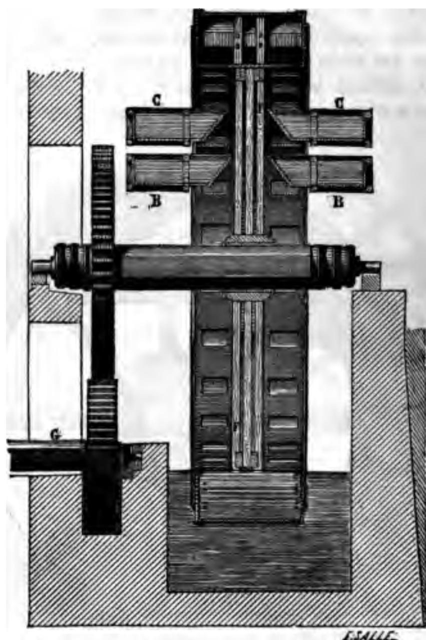


Fig. 112.

A wheel constructed upon this principle has been erected at Ciry-Salsogne, near Soissons, to raise water from the river Vesle for the purposes of irrigation. The engravings represent this wheel upon a scale of an inch to seven and a half feet. The channel B D (*fig.* 111.) supplied by the lower buckets conducts the water to the lower grounds, and C E to the higher.

182. **The tympan.** — A form of wheel, which has received this name, is also used in France for irrigation. This consists

of a hollow drum, to which rotation is imparted, and within which there are spiral partitions extending from the centre to the circumference, the sides being closed, but the edges open. Such a wheel is shown in *fig.* 113., with one of the sides removed, so as to show its interior.

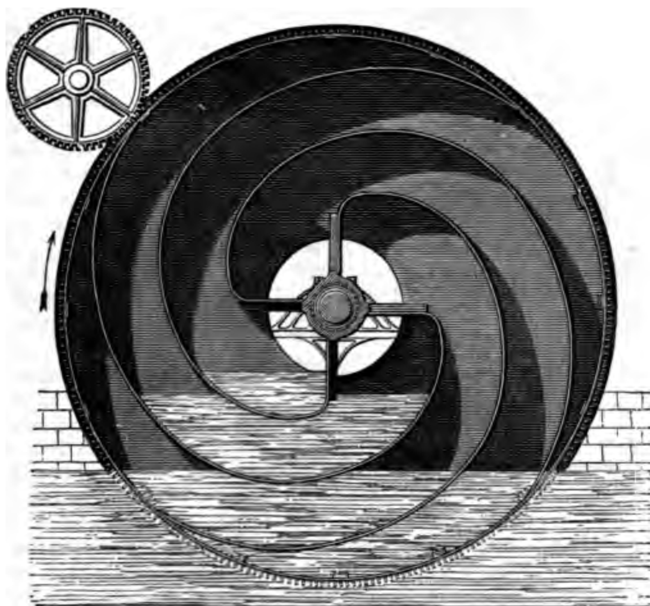


Fig. 113.

The edge of the drum is surrounded by teeth, which are driven by those of a smaller wheel, shown in the figure. The lowest part of the drum is immersed in the reservoir from which water is to be elevated. The water entering the partitions maintains there the same level as in the reservoir, so long as the partition is in communication with the water in the reservoir. But when by the revolution of the drum in the direction of the arrow the partitions become detached from the reservoir, the water is raised by them, and falls gradually towards the apertures round the axis, from which it is finally discharged at each side, as shown in *fig.* 114., which is an end section of the apparatus.

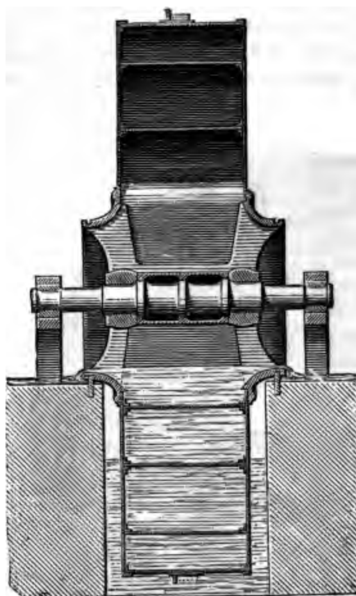


Fig. 114.

A wheel constructed on this principle is erected at Avignon, to raise water from the Rhône, for the irrigation of the rice-grounds of the Camargue. This wheel is represented by the figures upon a scale of 1 inch to 7½ feet.

183. **Mechanism to raise oil in lamps.** — In the better class of lamps used for dwelling-houses, a cylindrical wick is inserted in the burner, which is surrounded by a glass chimney, and passes between two brass tubes, the inner of which it surrounds, and by the outer of which it is surrounded. A sufficient space is left between the wick and this cylindrical casing for the oil to rise both inside and outside the wick, so as to keep it constantly saturated. A reservoir of oil is provided, from which the burner is thus supplied; the combustion is maintained by two currents of air, one of which ascends between the glass chimney and the external surface of the wick, and the other through the inner brass tube, passing therefore in contact with the inner surface of the wick. The cylindrical flame is thus supplied with air both on the outside and inside, to maintain the combustion.

One of the difficulties with which lampists have had to struggle was, to contrive means sufficiently simple and cheap, and not liable to derangement by the inevitable rough handling of servants, by which the burner should thus be constantly fed with oil, without interposing the feeding apparatus between the flame and the objects to be illuminated by it, — such apparatus being sufficiently capacious to enable the lamp to burn for a sufficient time without being replenished.

184. One of the first forms of lamps which was generally adopted in this country, is that represented in *fig.* 115., in which the reservoir is a hollow metal ring *aa*, surrounding the burner at

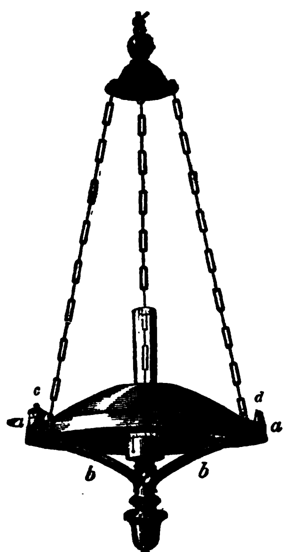


Fig. 115.

its own level. This ring is connected with the burner by two small pipes *b b*, through which the oil flows from the ring to the burner, rising in the latter to its level in the ring, and consequently the ring was fixed at the level of the top of the wick. An aperture is provided at *c*, with a screw stopper, through which the ring is replenished, and a small aperture is made at *d* for the admission and escape of air. The capacity of the ring was made sufficiently great to keep the level of the oil in the burner, subject to a very inconsiderable change, for some hours. In this lamp the principle is that upon which liquids maintain their level; the level of the oil in the ring and in the burner will necessarily be always the same. If, therefore, the greatest depth of the ring be half an inch, the level of the oil in the burner will be half an inch lower when the oil becomes exhausted than it was when the ring was full. But since much less than half an inch of level will produce a sensible effect upon the degree of saturation of the wick, and consequently upon the brilliancy of the flame, this species of lamp could never continue long without being replenished. The consequence of neglect of this operation would be the carbonisation of the wick, the evolution of smoke, and the diminution of light.

Another defect of these lamps arose from the shadow inevitably cast upon surrounding objects by the ring.

They have accordingly been superseded by various others, not subject to like defects.

185. **Carcel lamp.**—The objections to which the ring lamps, above described, are subject, have been removed by two species of mechanical lamps, both of which have come into very general use.

The Carcel lamp, thus named from its original inventor, is one in which the reservoir of oil can be placed at any desired level below that of the burner. The oil is pumped up through a pipe to the burner by a pair of small pumps of peculiar construction, the pistons of which are worked by the force of a main spring, transmitted to them through a system of wheel-work, the action being regulated and rendered uniform by a fly. The mechan-

ism is so regulated that the quantity of oil thus pumped up to the burner exceeds the consumption of the wick, and consequently flows over the edges of the burner, from which it is received into a pipe, from which it falls back into the reservoir, to be again pumped up.

Several advantages attend lamps constructed upon this principle; and although they have not obtained much circulation in this country, they have been universally adopted throughout all parts of the continent for the last half century. As there is no other limit to the distance of the reservoir below the burner than the power of the pumps, the lamp is susceptible of a great variety of graceful forms, and is completely sinumbral; its most usual form is that of an ornamental column, the reservoir and pumping apparatus being in its base, and the burner at its summit.

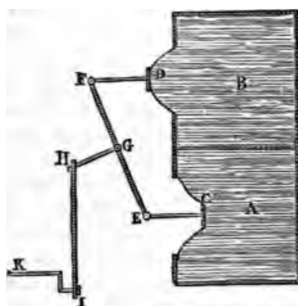


Fig. 116.

The manner in which the pumps are constructed is easily explained. Let A and B (*fig.* 116.) be two close compartments which are kept full of oil, supplied from the reservoir through two valves which open into them, and let these compartments be supposed to communicate by valves which open out of them, with two branches of the oil pipe, which leads upwards to the burner.

Let D and C be two small pistons, the rods of which are connected with a small beam E F, working on G as a centre. Let H G be an arm fixed at right angles to this beam, jointed at H to a rod H I, of which the extremity I is attached to a crank, which is kept in revolution by a shaft K. This shaft K receives its motion from the system of wheel-work above mentioned, which is impelled by a mainspring, and regulated by a fly.

As the crank I revolves, the rod H I is moved upwards and downwards, and imparts to the arm G H a corresponding motion, by which the pistons C and D are driven into and drawn out of the oil vessels A and B alternately. These pistons C and D do not move in cylinders, but are connected with the edges of apertures in the side of the oil vessels, of much greater magnitude than themselves, by a bladder-like membrane which the oil cannot penetrate. When either of these pistons is forced into the oil vessel, the oil which it displaces is forced through the valve into one or other branch of the oil pipe which leads to the burner, and when it is drawn out a corresponding quantity of oil enters through the valve, which opens inwards from the reservoir.

186. **The moderator lamp.** — The cost of construction of the lamp above described, and the expense and inconvenience of cleaning its mechanism, which is always necessary when it is laid by and has remained any length of time without use, has stimulated

nventors to contrive some equally efficient mechanism of greater implicity, and consequently of greater cheapness. This object as been realised in the lamps which have received the names of *noderators*.

In these, as in the Carcel lamps, the reservoir is placed below the burner to which the oil is driven up by the mechanical action of a spring.



Fig. 117.

The reservoir is a cylinder, as shown in *fig.* 117., in which a piston is fitted, the edges of which are formed of leather which are bent downwards, so that the oil cannot pass from the lower to the upper part, since its pressure against the leather would only render the contact of the latter with the cylinder still more oil-tight; but, on the other hand, if oil be above the piston it will force its way when pressed between the piston and the cylinder, and will pass below the former. Above the piston and attached to it at one end is a spiral spring made of strong wire, which at the upper end is fixed to the top of the cylinder. A rod, upon which a rack is constructed, passing downwards from the top of the lamp, is attached to the centre of the piston. The rack is driven by a pinion D, turned by a handle below the burner. The oil tube intended to carry oil to the burner, passing through the piston, descends below it, as shown at C. This tube consists of two parts one moving within the other like the tubes of a telescope, so that when the piston is drawn up, one of these tubes passes into the other, and when it descends it is drawn out.

Let us suppose the piston at the bottom of the cylinder, and let oil be poured in at the top of the lamp until the cylinder is filled. The spiral spring will then be completely immersed in oil. The pinion D is then worked by turning the handle, and the piston is drawn upwards; the spiral spring is compressed, and the oil forcing its way between the piston and the cylinder, passes below the piston. When the piston is brought to the top of the cylinder, the cylinder being full of oil and the spiral spring being compressed to its limits, the oil is pressed upwards with great force through the pipe C to the wick, and as more is driven up than is consumed by the burner it overflows, and falls back into the cylinder above the piston.

This continues until the piston, having driven up all the oil below it, arrives at the bottom of the cylinder. When this happens, the burner being no longer supplied, the lamp will cease to burn.

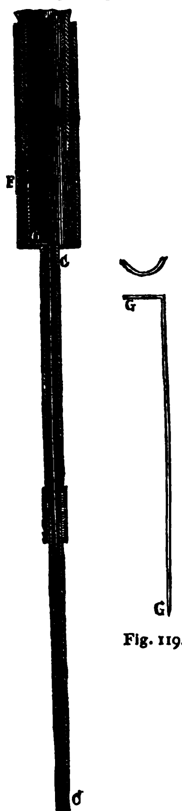


Fig. 119.

Fig. 118.

It will be evident that, since the force of the spring is gradually relaxed as the piston descends, the oil will be supplied to the wick at a gradually decreasing rate, and since sufficient for the combustion must be supplied to the last, a superfluous quantity must necessarily be driven up during the previous descent of the piston. The consequence of which is, that the lamp would require to be wound up at shorter intervals than would be necessary if some efficient expedient were adopted, like that of a fly or a balance wheel, to equalise the varying motion of the spring.

A very simple contrivance has accordingly been adapted for this purpose. Let F (*fig.* 118.) represent the burner, and C C the two oil pipes, one sliding within the other as already described, the lower one passing through the piston, and being attached to it. Let G G be a thin rod, shown separately in *fig.* 119., which descends into the oil tubes, and is attached to the bottom of the burner as shown in the figure. This rod, filling up the middle part of the oil tube, leaves around it a certain annular space through which the oil is forced up. As the piston ascends, the smaller of the two oil tubes ascends with it, and when the piston is at the top of the cylinder, the smaller tube fills the entire length of the greater; the space through which the oil is then forced by the piston, is that which surrounds the rod G G in the smaller tube. As the piston descends the smaller tube descends with it, and the portion of its length through which the rod G G passes, is continually less; while the portion of the greater tube through which the oil passes is continually greater. As the piston descends, therefore, and the spring relaxes, a greater space is opened, and a greater freedom of motion is given to the oil.

By properly regulating the proportion of the bores of the tubes, and the thickness and length of the rod G G, the freedom of the ascent of the oil to the

burner may be made to increase in a proportion nearly equal to the relaxation of the spring, so that a compensation will be obtained, which, for all practical purposes, may be considered as perfect.

Before these latter improvements in their construction were effected, the moderator lamps were subject to the great inconvenience of requiring to be wound up after very short intervals. The cheaper sort would burn for only two or three hours, and the larger or more efficient for four or five, without being wound up; but with the more recent improvements, lamps of this kind are constructed so as to require winding up only at intervals so great as twelve hours; they may, therefore, be fairly considered as possessing all the advantages of the Carcel lamp, while they are free from most of the objections to which the latter is subject.

187. **Water applied as a moving power.**—By the alternate processes of evaporation and condensation conducted on the surface of the earth upon a prodigious scale, its inhabitants have been furnished with an inexhaustible supply of moving power. The evaporation of the waters of the ocean mixes with the atmosphere over it enormous volumes of aqueous vapour, which, rising to the upper regions of the air, are attracted towards the more elevated parts of the land, where, by various physical agencies, they are reconverted into water and reprecipitated. From the summits and lofty plateaux they descend the declivities, forming first small streams and rivulets, which uniting, swell into rivers of greater or less magnitude. These, following the accidents of the land, flow along the valleys and plains, until finally they return to that vast basin from which they originated.

Such a descent of ponderous masses of water from the highest level of the land to the lowest level of the sea was a manifestation of the play of mechanical power, upon a scale so vast and a theatre so universal, that it could not long escape the notice of mankind, who were not slow, as civilisation and the arts advanced, to apply this power to the purposes of life.

Obvious as its play was, it required, nevertheless, various artificial expedients to subdue it to human uses. It rarely happens that the moving force of a stream can be directly applied to mechanical purposes. But whether so applied directly or indirectly, the first step towards its useful application is to ascertain the actual amount of moving power which it develops in each particular case.

The moving power of a watercourse being in all cases produced by the descent of water from a higher to a lower level, the perpendicular depth of this descent is the first element necessary for the appreciation of the power. If the current of a river at any two points, taken in its course, has a difference of 10 feet, the

water in passing from one point to the other must fall through that depth. If the difference of level be 20 feet, it will fall through twice the depth, and, if other things be the same, it will develop twice the amount of moving power.

But besides the depth of the fall, the quantity of water must be taken into account. If between two points, of which the difference of level is 10 feet, 1000 tons of water fall in a given time, while between two other points having the same difference of level 2000 tons fall, double the amount of moving force will be developed. In general, therefore, it may be stated that the total amount of moving force developed between any two points of a watercourse will be found by multiplying the weight of water which passes by the difference of the levels of the two points.

In the natural conditions under which streams, rivers, and other falls of water are exhibited, a considerable portion of the mechanical power thus produced by the descent of the liquid is absorbed by various causes of resistance encountered by the water in passing from the one level to the other, among which the most obvious are the friction of the bottom and banks of the stream, of the air at the surface, and all sudden change of direction incidental to the current. When the purpose is, therefore, to turn the moving power of the water to useful account, expedients are adopted to remove, or at least very much diminish, these causes of resistance.

188. The expedient by which this object is commonly attained consists in accumulating in one point, by means of a dam or flood-gate, the entire difference of level, which in the natural state of the stream is extended over a distance more or less considerable. By the establishment of such a dam, at any desired point, the current is momentarily stopped, and the water accumulates behind the dam until its level rises to the summit of the dam itself, when it overflows, and the current of the stream proceeds as before the dam was established, the quantity of water which falls over the dam in a given time being exactly equal to that which had previously passed the section of the stream where the dam is established in the same time.

By this expedient, therefore, the moving power of the current is developed between the summit and base of the dam, without any other loss of power than the very inconsiderable amount of friction at the summit of the dam and with the air in falling. The total amount of power developed will therefore be expressed by the weight of water passing over the summit of the dam multiplied by the difference of the levels of the water above and below the dam.

To render this moving power applicable, various mechanical expedients have been invented, the most important of which con-

sists of wheels mounted on shafts, to which they impart revolution when moved by the force of the water applied to their circumferences. The shafts to which revolution is thus imparted are placed in mechanical connection with the objects, whatever they may be, upon which it is desired to direct the force of the water.

189. These hydraulic wheels may, for the convenience of explanation, be resolved into two classes: first, those whose axes are horizontal; and second, those whose axes are vertical.

Hydraulic wheels, whose axes are horizontal, are of three kinds, differing one from another according to the point at which they receive the action of the water.

WHEELS WITH HORIZONTAL AXES.

190. **Undershot wheels.** — It is necessary to observe that, whether the water be allowed to overflow the dam and fall from the higher to the lower level, or to issue from an opening made in the dam at the lower level, or at any intermediate point between it and the higher level, the moving power developed will be precisely the same. This will be evident if it be considered that the force with which the water issues from an opening made at any point in the dam will be equal to that which it would acquire in falling from the higher level to the same point. The only difference between the case in which the water descends from the summit of the dam and that in which it issues from an opening made in it at any lower level is, that in the one case the power is gradually developed during the fall, and in the other it is accumulated and discharged at once in the volume of water issuing from the opening.

Whatever be the form of wheel used it is necessary to regulate the opening from which the water is discharged so as to direct it in a convenient manner upon the wheel, and this is usually accomplished by some form of sliding vane or flood-gate, which can be more or less opened or closed by suitable mechanism.

In the case now under consideration the wheel is erected so that the lowest point of its circumference shall correspond nearly with the level of the base of the dam, and a flood-gate is provided by which the quantity of water discharged upon the wheel can be regulated.

The circumference of the wheel is surrounded by a number of flat boards, called *float boards*, placed at equal distances, having their planes at right angles to that of the wheel and directed to its centre, as shown in *fig.* 120. The water issuing from the sluice-gate is projected against the float boards with the force that would

be acquired if it fell from the higher level, and it impels the float boards with corresponding force and causes the wheel to revolve.

Now it will be evident that, if the wheel were supposed to

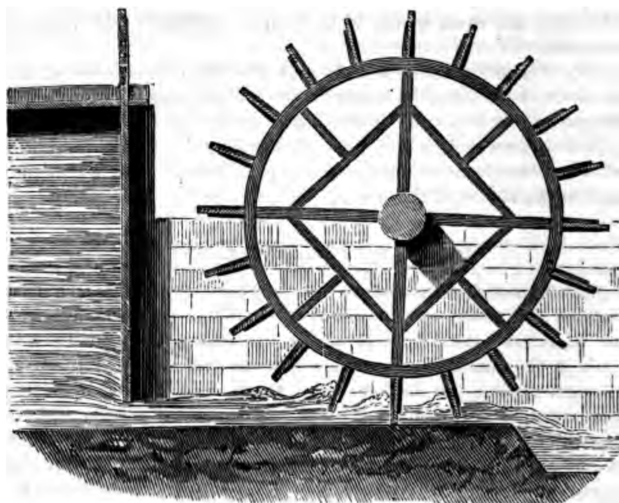


Fig. 120.

revolve at such a rate that the float boards shall move as fast as the water, no force whatever would be impressed upon the wheel, since the float boards in that case would merely move before the water, offering no resistance to it, and therefore suffering no reaction from it.

It may then be inferred that, if the velocity of the float boards were equal to that of the water, no force whatever would be imparted to the wheel, no resistance could be overcome by it, and consequently no useful effect would be produced.

If, however, the wheel be placed in connection with a weight to be raised by it, or any equivalent resistance, the moving force of the water will have a tendency to raise such weight or overcome such resistance, and if that moving force predominate, the wheel will be moved, the weight raised, and the resistance overcome. In this case, however, the velocity of the float boards will be less than that of the water, the force with which the water acts upon them being greater or less according as the velocity of the water more or less exceeds that of the float boards. This force, therefore, would be greater and greater as the resistance is

increased and the velocity of the wheel diminished, until at length the resistance might be so much increased as to balance the force of the water, and the wheel would stand still.

In this extreme case it is evident that the useful effect of the power would be nothing, inasmuch as it merely equilibrates with the resistance without moving it.

Thus we have two extreme cases, in both of which the power produces no useful effect;—the first, that in which the velocity of the float boards is equal to that of the water; and the second, that in which the wheel resists altogether the water, and does not move at all. In the former case there is no useful effect, because no resistance can be overcome, and in the latter there is no useful effect, because the resistance is not moved.

Between these two extremes there is obviously a maximum of useful effect. If we load the wheel with a very small weight it will be moved with a very considerable velocity, and the useful effect will be found by multiplying the weight by that velocity. If we increase the weight the velocity will decrease; but this decrease will be less in proportion than the increase of the weight, and therefore the useful effect will increase. This gradual increase of the useful effect will continue until the increase of the weight and the consequent decrease of the velocity have attained a certain point, after which it will decrease, and will continue to do so until the weight becomes so great as to resist altogether the power, when the wheel will cease to move and the useful effect become nothing.

It is found in practice that this point at which the useful effect becomes a maximum, is when the resistance is such that the velocity of the float boards shall be 45 per cent. of that of the stream.

The undershot wheel is by no means the most advantageous method of applying the power of water. In the first place, a certain amount of force is lost by the friction of the water against the surface of the water course, between the flood-gate and the wheel. Force is also lost by the sudden change of velocity which the water undergoes when it strikes the float boards; and, in fine, a further amount of force is left unemployed in the water, which escapes from the float boards having still a considerable velocity. The consequence of these, and other circumstances of less importance is, that not more than 25 per cent. of the moving power of the water is rendered available by wheels of this form.

191. **Overshot wheels.** — In this class of water wheels, the summit of the wheel is placed at or a little below the upper level of the water, which is let into the rim of the wheel by an opening in the dam or flood-gate, the extent of which can be regulated. The water is received into cavities, called buckets, formed in the

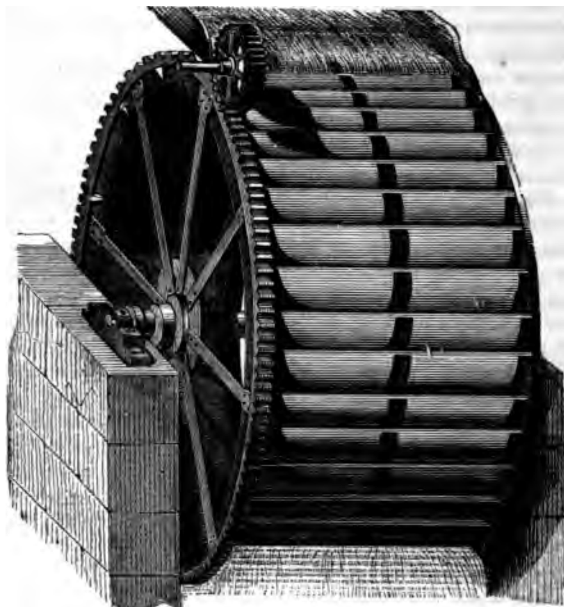


Fig. 121.

rim of the wheel, represented in perspective in *fig.* 121. Various forms are given to these buckets, three of which are shown in

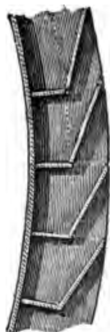


Fig. 122.



Fig. 123.



Fig. 124.

section in *figs.* 122, 123, 124. The wheel is moved by the weight of water contained in the buckets on the descending side of its

ertical diameter. The form of the buckets is so contrived as to etain as much of the water as possible until they arrive at the owest point of the wheel, where they empty themselves. As the ir which fills the buckets impedes more or less the entrance of the ater, and causes it to be scattered, different expedients are proided to facilitate its escape, one of which consists of making small oles in the buckets, not great enough to produce any considerable scape of the water. A better method, however, has been conrived by Mr. Fairbairn, who has constructed the buckets with paces behind them, for the escape of the air.

The slower the overshot wheel moves, the greater will be the seful effect. This arises from several causes: first, because the ater deposited on the top of the wheel can enter the buckets more lowly, thereby avoiding loss of power by a sudden change of peed; secondly, the water will be discharged at the lowest point f the wheel with very little velocity, so that all its descending orce will have been absorbed in the wheel; and, thirdly, no conderable quantity will be flung from the buckets in descending by entrifugal force.

It is found that wheels of this kind, when well constructed, tilise three fourths of the entire moving power. They are pplicable generally to falls, the height of which vary from ten o fifty feet.

In consequence of the slow motion of the wheel, it is usual to surround it with teeth, which drive a small toothed wheel as shown in the figure, the rotation of which will be more rapid than that of the water wheel, in the same proportion as its diameter is less.

The number of buckets surrounding the wheel increases with its diameter, but not in the same proportion. Machinists, as may be expected, are not in perfect accordance as to the proportion which ought to be maintained between the magnitude of the wheel and the number of buckets; but the following table may be regarded as representing the average practice: —

Diameter of Wheel Feet.	Number of Buckets.
10	24
13	36
17	44
20	56
26	76
34	96
40	108

192. **Breast wheels.** — This class of water wheels resemble in their form and construction the undershot wheel — the float boards, however, being closer together. The water enters at some point between the vertical and horizontal diameters, nearer to the latter than the former. It acts by a combination of impulse

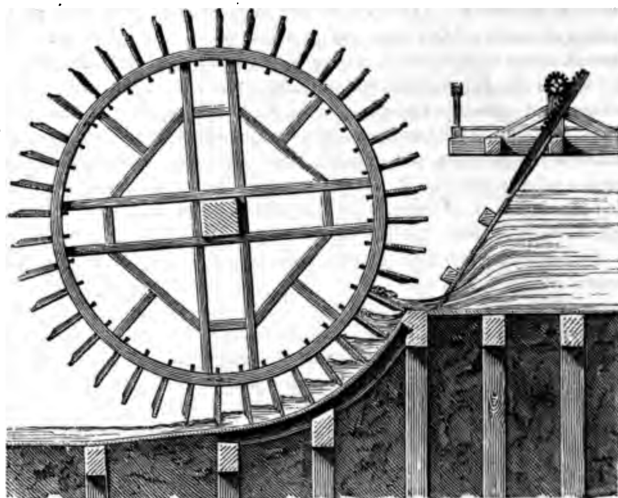


Fig. 125.

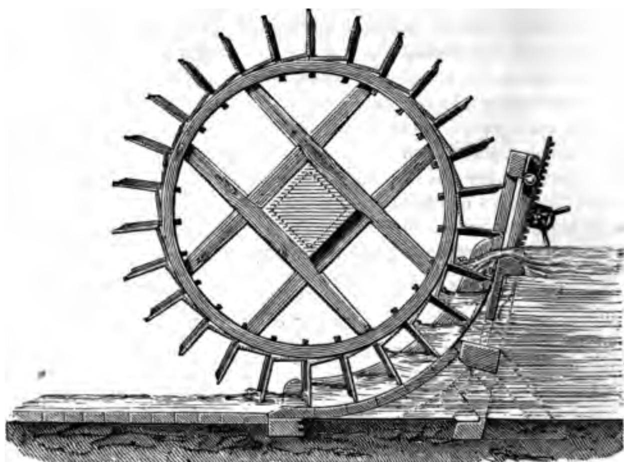


Fig. 126.

and weight. The float boards move in a curved channel corresponding with them in form and magnitude, but without touching its bottom or sides. In *figs.* 125. and 126., where two such wheels

presented, the sides of this channel are omitted, to show the
r in which the water acts upon the float boards. In the one
he water is admitted nearer to the horizontal diameter than
other, and acts with greater effect.

wheel has the advantage over the undershot wheel, of act-
the weight of the water as well as by its impulse, less power
lost also by the force of the water discharged from its lowest
Compared with the overshot wheel, it has the advantage of
ing so much loaded with the weight of the water, and there-
ot producing so much strain and friction on its bearings.
und in practice when well constructed to utilise 65 per cent.
moving power.

. **Poncelet's wheel.** — This wheel, which takes its name
he eminent French engineer who first constructed it, is an
hot wheel, having curved buckets, as represented in *fig.* 127.

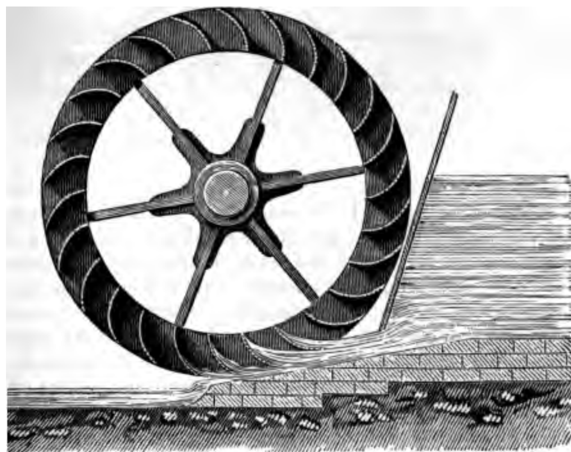


Fig. 127.

fect of this form of bucket is to diminish the loss of power,
attends the sudden shock of the water against the float
of the common undershot wheel, and the force retained by
ter after leaving the wheel. Instead of a sudden impact,
ter entering the buckets encounters no flat surface, but
s gradually up their curved sides, and in leaving them
ds gradually down the same sides.

found that the greatest useful effect is produced by this
when the velocity of its circumference is 55 per cent. of the

velocity of the stream, and that from 50 to 60 per cent. of the moving power is utilised by it.

194. **Wheel driven by an indefinite current.**— It sometimes happens that a moving power is derived from the current of a river, by means of a simple paddle wheel (*fig.* 128.) attached to

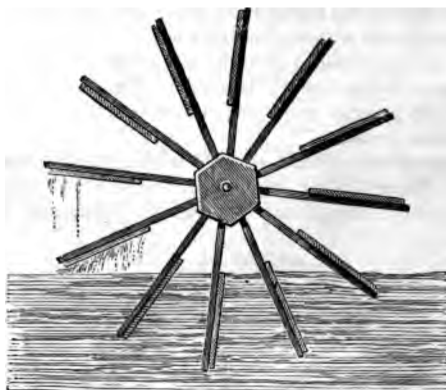


Fig. 128.

a boat moored in it. In this case the force of the stream, acting on the paddle boards, imparts revolution to a shaft extending across the boat, in which the machine driven by the shaft may be erected. Two paddle wheels may be placed on the same shaft at different sides of the boat, as in a steam-boat.

Since in all cases of the application of this form of wheel, simplicity and cheapness are paramount objects, it will not be necessary here to enter into any discussion as to the relative efficiency of different paddle boards.

The useful effect is found to be greatest when the velocity of the paddle boards is about 40 per cent. of that of the stream.

WHEELS WITH VERTICAL AXES.

195. The mill-stones in corn mills having the axis round which they are turned vertical, much simplicity is given to the mechanism wherever the axis of the wheel upon which the moving power immediately acts can be also vertical. On this account, horizontal water wheels, with vertical axes, have always been much used in the corn producing provinces of France and other parts of Europe; and within the last quarter of a century such improve-

ments have been made in them, that the performance of many of them may now be regarded as equal to that of any other hydraulic wheel.

We shall here explain a few of the most important of the wheels constructed on this principle.

196. **Spoon wheel.** —A horizontal wheel which has been much used in France, called *roue à cuiller*, or *spoon wheel*, is shown in *fig.* 129.

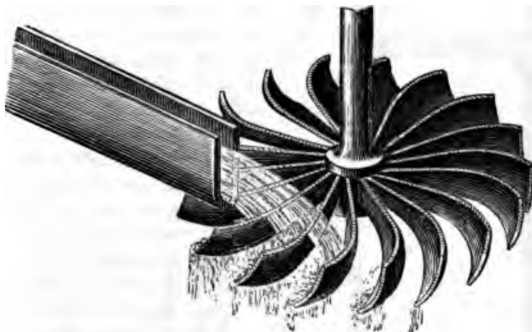


Fig. 129.

These wheels consist of a number of spoon-shaped arms, diverging from the nave and presenting their concave sides to water projected against them by a spout proceeding from a reservoir. It is found that the best effect is produced when the velocity of the wheel is 70 per cent. of that of the water.

These wheels are found convenient in consequence of their great simplicity, where there is not a great supply of water.

197. **Cistern wheels.** — This is a form of horizontal wheel shown in *fig.* 130., the form of the wheel corresponding nearly with that above described. The wheel, however, in this case is fixed in the bottom of a cylindrical cavity made to receive it. The water flows into the cavity through a channel, whose direction is that of a tangent to the wheel, and after driving the wheel round, falls through an opening provided for

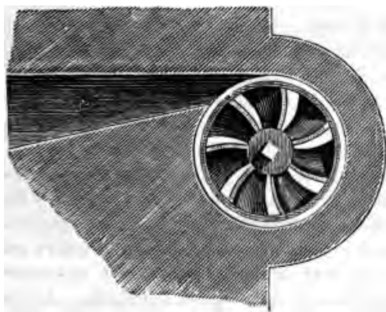


Fig. 130.

the purpose to a lower level. This wheel is subject to much friction and leakage, and when constructed in the best manner does not utilise so much as 25 per cent. of the power.

198. **Wheel of recoil.**—This form of wheel, which has been generally denominated by English writers as Barker's mill, is represented in the form of a model in *fig.* 131. A vessel containing water is mounted so as to turn freely round a vertical axis; the water passes into a horizontal tube, which at its extremities is bent in contrary directions, so as to let the water issue from it, as shown in the figure, in the direction of tangents to the circle of which the tube is the diameter. The water discharged reacts upon the tube upon the same principle as the discharge of a gun produces a recoil, and a tube is accordingly made to revolve round the vertical axis.

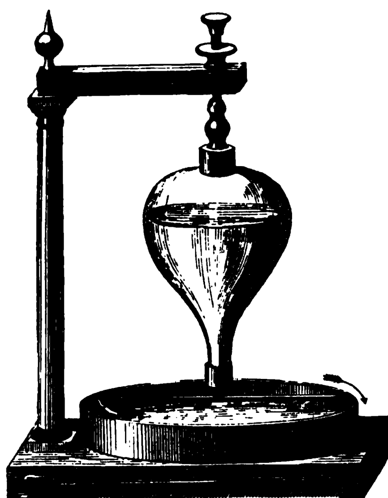


Fig. 131.

Various applications of this principle may be seen in *jets d'eau* and ornamental waterworks; but as it is never applied in the industrial arts, so far as we know, it will not be necessary to notice it further here.

199. **The tourbine of Fourneyron.**—By far the most important class of hydraulic wheels with vertical axes are those which have received the name of tourbines, and have been greatly improved and extensively applied in France.

The first of these, by which the attention of the engineering world was attracted, was one erected by Fourneyron.

This machine may be briefly described as a subaqueous horizontal wheel, revolving round a vertical axis, which, rising above the surface of the water in which the wheel is submerged, imparts motion to any machinery which is required to be driven. There are two reservoirs of water placed at different levels, and the water flows from the higher to the lower level through a cylinder, the top of which is open and in communication with the higher level, and

the bottom of which is closed by a solid circular plate, but surrounded at the sides by an annular opening, from which the water pressed downwards through the cylinder from the higher level issues horizontally in every direction round the cylinder. This lateral circular opening is surrounded by a horizontal wheel, capable of turning on its centre round the cylinder, and this wheel has its rim formed into curved compartments, exactly similar to those of Poncelet's wheel, shown in *fig.* 127. The water, issuing in directions diverging from the centre of the cylinder, reacts upon the curved surfaces of all the compartments of the wheel, so as to make it revolve in the direction of their convex sides. This wheel is supported by a circular plate placed under the cylinder which is attached to a vertical axis, which rises through the cylinder and to which it imparts motion.

This general description being understood, the section of the apparatus shown in *fig.* 132. will be more easily comprehended.

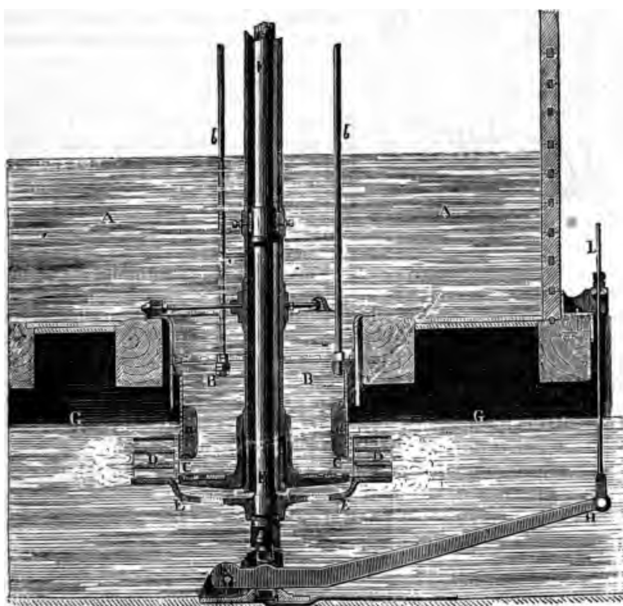


Fig. 132.

The upper reservoir is shown at A A, and the stage separating it from the lower reservoir at G G. The cylinder B B communicates between the two

reservoirs through the lateral opening C C, which, though represented in the section as two apertures diametrically opposed, must be understood as a circular opening surrounding the cylinder just above the bottom. A short cylinder, with rounded corners, represented in section at *a a*, slides within the great cylinder B B, and can be moved by the rods *b b*. By this means, the width of the circular opening C C can be increased or diminished at pleasure.

The wheel surrounding the opening C C is shown in section at D D, and the plate which surrounds it, E E, is attached to an axis F F, to which it imparts revolution. This axis is supported on a pivot formed upon a lever H K, at a point not far from the fulcrum K. The long arm of this lever is jointed at H to a rod H L, which can be raised and lowered by a screw and nut at its upper end. By this means, the axis F F, together with the wheel D D, can be raised and lowered, so that the openings of the compartments of the wheel can always be made to correspond with the circular opening of the cylinder.

According to what has been explained above, it would appear that the water would issue from the cylinder upon the wheel in directions diverging from the centre, and such a motion would impart revolution to the wheel; but the machine has been rendered more efficient by dividing that part of the bottom of the cylinder, which corresponds with the opening C C, into curved compartments of the form represented in *fig.* 133., where B represents the section of the bottom of the cylinder, and D that of the surrounding wheel. By this expedient the water, instead of issuing radially from the cylinder, issues from it tangentially, the consequence of which is that the machine acquires greatly increased efficiency.



Fig. 133.

If the width of the opening C C be rendered less than the height of the curved compartments D D (*fig.* 132.) of the wheel, the water issuing from the opening C C, and filling that portion of the wheel which is above the edges of the sliding cylinder *a a*, would be carried round with the wheel without at all contributing to its motion. This circumstance has been prevented by dividing the wheel into a succession of stages, by horizontal compartments one placed over the other, the section of which is shown in *fig.* 133. By this expedient, the water issuing from C C would only enter those compartments which correspond with the lateral opening of the cylinder.

This wheel possesses an obvious advantage over Poncelet's undershot wheel, with which it is identical in form. In the latter the water ascends as it enters and descends as it leaves the buckets, thereby producing eddies and forces which are mutually destructive. In the tourbine wheel, however, the water entering the bucket on the inside and leaving it on the outside, produces an uniform and uninterrupted action upon the wheel.

In the case of all horizontal wheels, the impelling force acting only on one side of the centre, necessarily produces a pressure and strain upon the axle, and consequent friction and resistance. In

the tourbine, on the contrary, the impelling forces, acting equally on every part of the circumference, their components directed upon the axis must mutually balance each other, and, consequently, no strain or pressure is produced.

Another very obvious advantage which attends this, and, indeed, all submerged wheels, is, that their performance is uninterrupted either by floods or droughts, provided only that sufficient water remains to cover the wheel. Neither is their operation suspended by the congelation of watercourses in severe frosts, such congelations being merely superficial.

Experience on a large scale has accordingly shown that from 75 to 80 per cent. of the entire power of the water is utilised by these wheels.

Another striking advantage which attends them is, that any given departure from the velocity which produces the greatest useful effect, will produce a much less decrease of useful effect than in any other species of water wheel. This result is of the highest practical importance in all cases where it is necessary to maintain a speed nearly constant, while the height of the fall may be subject to much variation.

This is the only form of hydraulic wheel which can be applied with equal efficiency whatever be the height of the fall. M. Fourneyron, the inventor, erected a tourbine at Sainte-Blaise, in the Black Forest, which was moved by a fall having a height of about 350 feet. The wheel, whose diameter was only 22 inches, made 2300 revolutions per minute, and produced a 40 horse power, utilising three fourths of the whole power of the water.

A case presenting the other extreme is offered by a tourbine established at Gisors, under a fall the height of which varied from 1 to 3½ feet. With a fall of 3½ feet, three fourths of the power, with one of 2 feet, two thirds, and with one of 1 foot, six tenths of the entire power were utilised.

200. **Callon's tourbine.** — The division of the wheel into a succession of stages by horizontal partitions, affording only an imperfect remedy for the inconvenience it professes to remove, M. Callon invented another expedient for limiting the flow of water into the compartments of the wheel. Instead of the sliding cylinder *a a* (*fig.* 132.) already described, he substituted a series of sliding shutters surrounding the opening. By letting down all of these, the opening c c might be entirely closed, and by letting down any proposed number of them, equally distant one from another, a number of separate openings with closed intervals between them would be formed, instead of a continuous opening. By this expedient the water is let into the entire depth of the wheel, and no horizontal partitions are required. But another

inconvenience is produced, which is, that at the moment when the buckets pass the closed shutters, the water contained in them cannot continue to be moved outwards without leaving a vacuum behind it, — a circumstance which suddenly retards its motion, and robs the wheel of a corresponding proportion of power.

201. **Fontaine's tourbine.** — One of the most improved forms of this class of wheels is one which was shown in the Crystal Palace in Hyde Park in 1851, invented by M. Fontaine, and constructed by Messrs. Fromont and Son, of Chartres, in France.

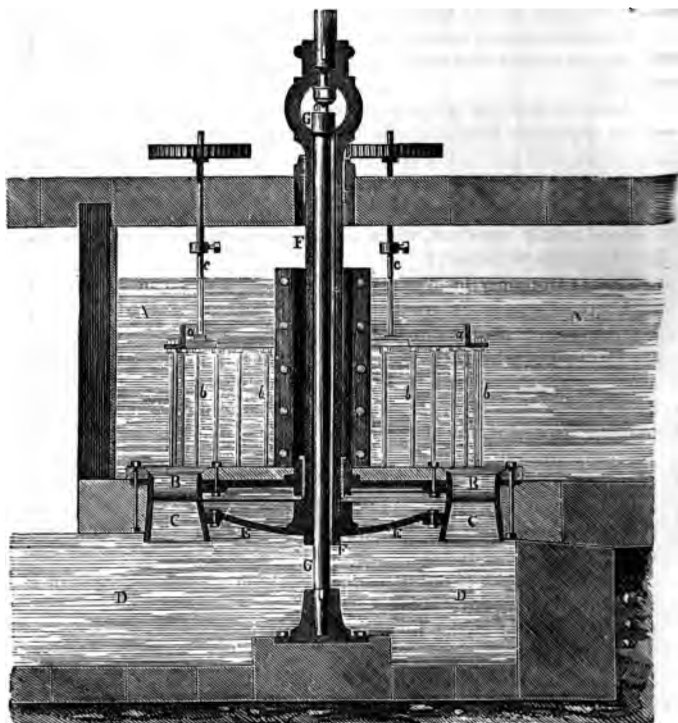


Fig. 134.

In the tourbine of M. Fourneyron, the water strikes the curved compartments of the wheel horizontally, these compartments being placed vertically. In the tourbine of M. Fontaine the curved compartments receive the water falling vertically upon them, and being inclined to it by reason of their curvature, one of the com-

ponents of the pressure of the water acts upon them at right angles to the radius of the wheel, and therefore produces revolution.

A vertical section of this tourbine is shown in *fig.* 134., and another vertical section of a part of the wheel, made by a plane at right angles to the radius, is shown in *fig.* 135.



Fig. 135.

The water falls from the upper reservoir A A to the lower reservoir D D, through a circular opening which is occupied by the wheel B C, B C, and which appears in section only in the figure. The wheel is connected with a tubular axis F F, by a circular disc E E. This tubular axis is suspended on the summit of a cylindrical arbor G G, upon which it can turn freely, and round which it is perfectly balanced. The wheel, filling the circular opening, is divided by curved partitions into a number of separate compartments *f f f* (*fig.* 135.), to which the water is supplied through openings *e e*, curved in the contrary direction, so as to strike nearly perpendicular upon the partitions *f f f*. The passages *e e e* receive water from large openings *d d*, which can be more or less uncovered by shutters moved by the rods *b b b*. These rods are attached to a circular frame *a a*, which can be raised and lowered by screws provided for that purpose.

This tourbine, which is attended with many practical advantages, is found, like that of M. Fourneyron, to utilise from 70 to 80 per cent. of the whole power.

The advantages which may be fairly ascribed to this new class of hydraulic engine, are —

1°. That it occupies a small space.

2°. That, turning with great speed, it may, when applied to flour mills, be made to communicate the motion directly to the mill-stones.

3°. It works under water.

4°. It works with nearly the same efficiency, whether the fall be great or small.

5°. It utilises, in all circumstances, as much of the moving power as is utilised by the most efficient hydraulic machine, under the most advantageous circumstances.

6°. In fine, its velocity may be considerably varied, without producing much change in its efficiency.

202. **Water-engine.** — Although hydraulic wheels of one or other of the various forms above described, are by far the most common expedients by which water power is applied, they are not the only ones, and in certain exceptional cases, other mechanical

combinations have the advantage over them. When, for example, a fall of water is presented of great height but very small in quantity, it is often found convenient to apply its power to impart motion to a piston in a cylinder by mechanical arrangements similar in principle to those which govern the motion of the piston of a steam-engine, and, like the steam-engine, the piston of the water-engine may be impelled by the power in one direction only, or may be alternately driven in both directions. In the former case, the machine is called a *single-acting engine*, and in the latter a *double-acting engine*.

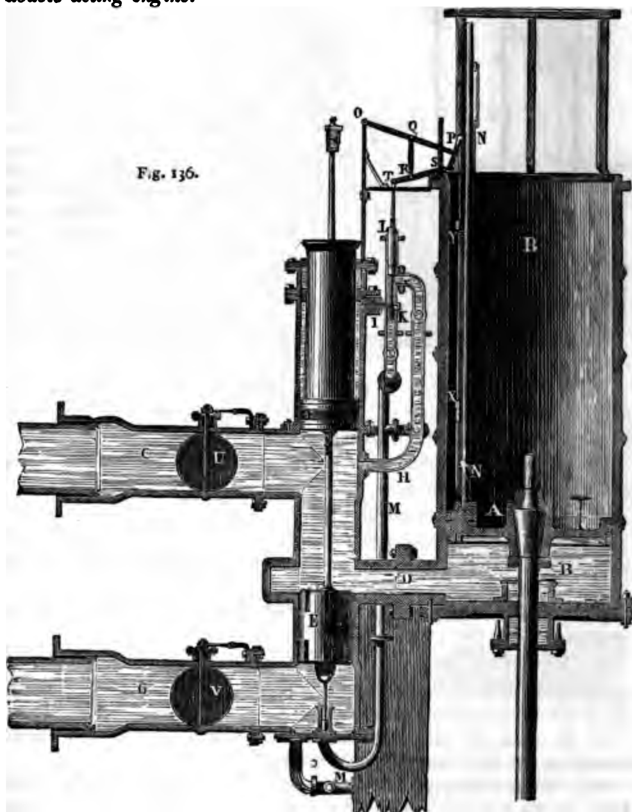


Fig. 136.

203. **Single-acting water-engine.**—In *fig.* 136. is given a section of an engine of this class, two of which have been erected

by Mr. Juncker, at the lead and silver mines of Huelgoat, in Brittany.



Fig. 137.

A piston A moves in a cylinder B B, the upper end of which is open The rod, being presented downwards, moves through a water-tight collar in the bottom of the cylinder. The water, by the pressure of which the piston is moved, flows through a pipe C, from a reservoir placed at a higher level; and, after it is discharged from the cylinder, flows away through another pipe G, to a reservoir at a lower level. Throttle-valves, U and V, are placed in the supply and discharge pipes C and G, by which the quantity of water passing through them can be controlled and regulated. These valves are circular metallic plates, which, when placed with their edges in the direction of the axes of the pipes, leave free course to the water, and when placed at right angles to the axes, stop it altogether. In intermediate positions they allow more or less of the water to pass. Two solid pistons, E and F, move in a vertical tube, extending above the mouth of pipe C, and below that of the passage D. These two pistons are attached to a common rod, and are moved together. In the position of the apparatus shown in *fig.* 136., the valves U and V being both turned with their edges in the direction of the axes of the pipes, the water flows freely from C through D below the piston, and presses it upwards in the cylinder, with the force due to the difference between the level of the piston and that of the reservoir from which water is supplied. The piston being thus moved to the top of the cylinder, and consequently the cylinder filled with water, the pistons E F are drawn upvards until the bottom of E has been raised above the passage D. This iston E will then intercept the communication between D and C, and leave pen the communication between D and G, as shown in *fig.* 137. The level of he lower reservoir being below that of the pipe G, the water will fall by ts gravity from the cylinder, through the passage D and the pipe G to hat reservoir, and the piston will descend by its weight.

When the piston has arrived at the bottom of the cylinder, the small piston : is again let down, so as to take the position shown in *fig.* 136., when water gain flows from C into the cylinder, and the piston is again forced up.

In this manner, by moving alternately the piston E above and below the pening D, the water is alternately admitted to the cylinder B, from the pipe ; and discharged from it through the pipe G, and the piston is thus alterately moved from the bottom to the top of the cylinder, by the pressure of he water in the upper reservoir, and moved back from top to bottom by its wn weight.

The piston E, by the alternate motion of which upwards and downwards, the action of the water on the great piston A is regulated, is moved by the force of the piston A itself, by means of the apparatus which appears in the figure on the left of the cylinder B.

A curved pipe H, proceeding from the end of the supply pipe, leads to a small vertical pipe K L, from the side of which a passage leads, through which water is admitted to the cylinder in which the piston F moves. The upper part of this piston F consists of a cylindrical rod of less diameter than E, while the diameter of the piston F itself is greater than that of E. The pipe L K, at its lowest point, enters another vertical pipe M M, which, descending below the discharge pipe, is bent upwards, and enters the latter pipe at a point directly under the centre of the piston E. Over the opening a small cylinder is placed, in which a plug is inserted, the rod of which is connected with the base of the piston E. When the piston E is in its lowest position, this plug descends into the cylinder, closing the mouth of the pipe M M, as shown in *fig.* 136. But when E is raised above the passage D, the plug is drawn up, and the pipe M M is in free communication with the discharge pipe G.

A small piston is moved in the pipe L K. When it is below the passage I, water from the supply pipe C will flow freely through the curved pipe H and the passage I, to the annular space above the piston F. But when the small piston in L K is moved above the passage I, the communication between that passage and the pipe H is intercepted, while its communication with the pipe M M is opened. The rod of the small piston in L K is jointed at T to the extremity of a small lever S T, which plays on the centre S. A rod Q R is jointed at R to the lever S T, and at Q to a lever O P, which turns on the centre O. At the end P of this lever there is a small arch, shown in the figures, from the extremities of which, on opposite sides, two pins project. To the great piston A a vertical rod N N is attached, which moves upwards and downwards with it, through guides made in the framing above the cylinder. On different sides of this rod two cams are attached at X and Y, one of which strikes one of the pins projecting from the lever O P, when the piston approaches the top of the cylinder, so as to push the lever O P upwards, and consequently to draw the piston in the pipe L K above the passage I. When the piston, on the contrary, approaches the bottom of the cylinder, the other cam on the rod N N, striking the other pin on the lever O P, pushes that lever, and consequently the piston in the pipe L K, downwards, so that that piston, descending below the passage I, leaves that passage in free communication with the pipe H.

Thus it appears that whenever the piston is at the bottom of the cylinder, the water above the piston F is in free communication with that of the supply pipe C, through the pipe H, and whenever it arrives at the top of the cylinder, the same water is in free communication with the water in the discharge pipe G through the pipe M M.

It remains now only to show how the piston E is moved alternately above and below the passage D.

When the piston A is in the position shown in *fig.* 136., the pressure of the water coming from the supply pipe forces it upwards; meanwhile, the piston E remains immovable because the effective downward pressure on the surfaces of the connected pistons E and F is greater than the upward pressure. This object is attained by making the diameter of the piston F greater, and that of the cylindrical rod above it less, than the diameter of the piston E. The piston F will then be pressed upwards by a force proportionate to the

difference between the area of its base, and so much of the area of its upper surface as is covered with water; that is, in fact, with a force proportionate to the sectional area of the cylindrical rod attached to the top of the piston F. Meanwhile, the connected pistons E and F are pressed downwards by the water from the supply pipe with a force proportionate to the sectional area of the piston E; but as this sectional area is greater than that of the cylindrical rod attached to the piston F, the force which presses down the connected pistons is greater than that which presses them up, and the piston E is therefore retained in its position below the opening D, as shown in *fig.* 136., while the great piston A is forced to the top of the cylinder.

But in arriving at the top of the cylinder, the piston A, by the means already explained, moves the small piston in L K above the passage I, and thereby cuts off the communication between the water above F and that in the supply pipe, while it opens the communication between the same water and the pipe M M. The force with which the water in the supply pipe acts on the base of the piston F, being now no longer opposed by the corresponding pressure of the water above F, the upward pressure on F will be greater than the downward pressure on E, in the same proportion as the sectional area of F is greater than that of E, and consequently the connected pistons E and F will be moved upwards until the piston E passes the opening D, and takes the position shown in *fig.* 137. The water then flows from the cylinder B, through D, and the discharge pipe G, to the lower reservoir, and the piston descends by its weight to the bottom of the cylinder.

In the same manner the alternate motion of the engine is continued indefinitely, by means of the self-acting mechanism here described, placed between the great cylinder and the passages in which the pistons E and F are moved.

In passing the opening D, the piston E would be subject to a considerable lateral pressure, proceeding from the reaction of the piston transmitted through the water, and this pressure would be productive of more or less friction or resistance. This is prevented by surrounding the piston E with a groove by which the water is allowed to flow freely all around it, the pressure being thus rendered equal in every direction, and therefore self-neutralised.

To render the access and discharge of the water in the passage D gradual, a number of grooves are formed in the top and bottom of the piston E, as shown in the figures, so that the water enters and leaves these grooves gradually, as the piston passes the opening D.

The figures represent the two machines erected at Huelgoat, upon a scale of 1 inch to 3 feet 9 inches. They are moved by a column of water 200 feet high. Their pistons are connected with a long vertical rod, which descends into a shaft, where it works a pump for the drainage of the mine, by which the water is raised from that level to a height of 750 feet. To assist the motion of the great pistons in descending, the machines are erected at a level about 46 feet lower than the gallery by which the water is discharged, so that the descent of the piston is aided by the weight of a corresponding column of water.

It is found that in the practical working of these machines, nearly two thirds of the moving power is utilised.

204. **Double-acting water-engine.** — This machine is much more simple in its structure and operation than the single-acting engine. It is represented in section in *fig.* 138.

Fig. 138.

The supply pipe E E, descending from the upper reservoir, communicates with the top and bottom of the cylinder by the horizontal pipes F and G, and the lateral openings C and D. A lateral discharge pipe is provided at L by which the water, after it has worked the piston, is thrown into the lower reservoir M. Two solid pistons H and K are connected together, and with a third piston N, of greater diameter, by a common piston rod. In the position represented in the figure, the water from the supply pipe E E, passes freely to the bottom of the cylinder through G and D, and presses the piston up. It is intercepted, however, from the top of the cylinder by the piston H. While

the piston A, therefore, is driven upwards by the water from the supply pipe, the water which was above it is discharged by the passage C and the pipe L into the lower reservoir M. When the piston A arrives at the top of the cylinder, the small pistons H and K are moved down, until H descends below the passage C, and K below the passage D. The water then flows freely from the supply pipe E through F and C to the top of the piston, while it is intercepted by K from the bottom, but allowed to flow freely through D and L into the lower reservoir M. The piston is, therefore, pressed down, and when it arrives at the bottom of the cylinder, the position of H and K is again changed and restored to that which they have in the figure. In this way the alternate motion of the piston A, upwards and downwards in the cylinder B B, is continued indefinitely by the alternate change of position of the pistons H and K.

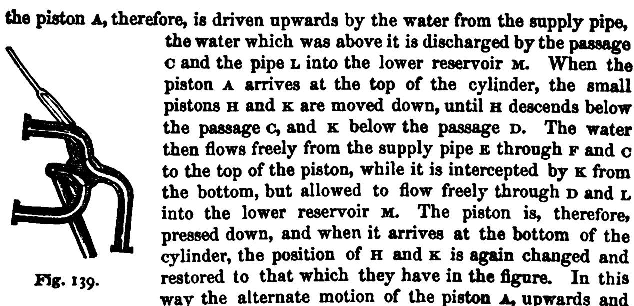


Fig. 139.

It remains, therefore, only to show how the change of position of H and K is produced.

The great piston A has two rods: that which is presented downwards drives whatever machinery the engine is applied to move; that which is presented upwards works the small pistons H and K by means of the larger piston N already mentioned. This piston N moves in a small cylinder, into which there are lateral pipes of communication, P and Q, at top and bottom. These pipes communicate with a cock O, called a *fourway cock*, which has the property of causing the pipes P and Q, according as its position is changed, to communicate alternately with the supply pipe F, and the lower reservoir M. In the position represented in *fig.* 138., the pipe Q is in communication with the supply pipe F by the pipe R, and the pipe P is in communication with the reservoir M by the pipe S. When the piston A arrives at the top of the cylinder, the upper piston rod, acting upon the fourway cock O by means of the connecting lever T, will turn it into the position shown in *fig.* 139., in which Q will communicate with S and M, and P with R and F. The piston N will, therefore, be pressed down by the force of the water in F, while the water below it will be discharged through Q and S into M. The piston N being therefore pressed down to Q, H and K will be driven below the passages C and D, and they will assume the position necessary to produce the descent of the piston A.

In the same manner, when the piston A arrives at the bottom of the cylinder, the upper piston rod draws the lever T, so as to turn the fourway cock again into the position shown in *fig.* 138., and in the same manner the motion of the engine is indefinitely continued.

205. **Hydraulic ram.** — The water-engine thus called was the invention of Montgolfier, whose fame has been more popularly diffused by his invention of balloons rendered buoyant by heated air. In *fig.* 140. is presented a section of the original machine erected by Montgolfier himself, which still exists in the château of *La Celle Saint Cloud*, near Paris. It was constructed to supply water to that establishment.

The engraving represents the machine upon a scale of 1 inch to 7 feet.

The water arrives from a reservoir at a higher level by a horizontal pipe A. Over this pipe there is a circular opening, in which a valve B is placed, which, when pressed upwards, stops the opening. Further on the pipe ascends into a small reservoir C, the upper part of which is filled with air, which is compressed there by the water ascending in it. This water, by its lateral pressure, opens the valves E E, and enters the larger reservoir F, which it partially fills, compressing the air which is confined in the upper part of it. The reaction of this air upon the surface of the water causes the water to rise in the force pipe G.

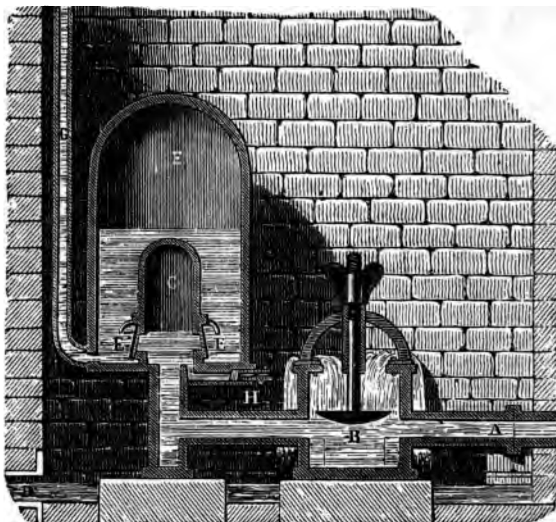


Fig. 140.

When the valve B is down, as shown in the figure, the water overflows the opening above it, and flows off into a waste reservoir. This escape of the water produces a rapid increase of the velocity of the current in A, so that that current, acting upon the under surface of the valve B, forces it up and closes the opening by which the water escapes. The water, being thus momentarily confined, forces its way into the cylinder C, where it compresses the air and produces a reaction which opens the valves E E, and a certain quantity of water enters the vessel F, and further compresses the air. These resistances soon retard the current in A, and relieve the valve B from the impulse which raised it. That valve again falls, and the valves E E are closed. The water again escaping from the opening over B, the current in A is once more accelerated, and B is again closed and the same series of effects ensue as have been already described.

By the continuance of this action water is continually elevated in the pipe G.

Since water has the property of absorbing air, the air compressed in the

c and F would, after a certain time, be carried away in the water through the force pipe G; and although the machine would continue n the absence of the air, its action would not be so uniform, and would ect to certain shocks which would have the effect of diminishing the ;y of the engine and accelerating its wear. To prevent this an air ; provided at H, which, opening inwards, admits air, which is sucked ı it during the intervals when the valve B is opened.

hydraulic ram, when well constructed, is capable of utilising 60 per cent. of the moving power.

BOOK THE SECOND.

PNEUMATICS.

CHAPTER I.

GENERAL PROPERTIES OF GASES.

206. **Atmospheric air, the type of all gases.**—The class of bodies which exist in, or may be reduced to, the form of elastic fluids, or the aeriform state, are extremely numerous; indeed, it is probable that all bodies whatever, either by heat, or other physical agents, may be converted into this form. The most universally observable substance of this class is atmospheric air. Many of the qualities found in this substance extend, without modification, to all elastic fluids whatever; but there are some of them, especially when applied to vapours, which require to be restricted and modified by various circumstances, which will be explained hereafter. There are also many circumstances to be attended to in explaining the properties of various gases which belong to the department of chemistry, in which the production and constitution of these gases are explained. Our present object is limited to the investigation of the mechanical properties of the atmosphere; it being, however, understood that the various theorems which we shall establish may be carried into other departments of physics, and applied to all bodies whatever in the gaseous form, subject to restrictions and modifications peculiar to the vapours and various species of gases to which they may be applied.

Air possesses, in common with all material substances, the qualities of impenetrability, inertia, and weight.

It possesses, in common with liquids, the characteristic properties of fluids, such as the free motion of its particles amongst each other, and the power of transmitting pressure equally in every direction. It possesses, also, its own characteristic properties of compressibility and elasticity, which distinguish it from solids and liquids.

From its extremely attenuated nature, its great levity, the facility with which it is displaced, the ease with which bodies pass through it, and its extreme transparency, which renders it imperceptible to sight, it might be, and in fact was, doubted whether air were material; and hence the word spirit, from *spiritus* (*air* or *breath*), came to signify an immaterial substance. Nevertheless, it requires but little reflection on the phenomena of nature, as will presently appear, to become convinced that air possesses all the fundamental qualities of matter.

207. **Air impenetrable.** — Impenetrability is that quality in virtue of which a body excludes all others from the space it occupies. If a hollow vessel, such, for example, as a glass tumbler, be inverted and immersed with its mouth downwards in water, it will be found that the water will not fill the tumbler. Let a cork be placed upon the water under the mouth of the tumbler; and when the tumbler sinks, the cork and the surface on which it floats will sink too.

208. **Air has inertia.** — Inertia is manifested by the moving force which matter has when it is in motion, or by the resistance which matter at rest offers to other matter in motion which encounters it. Air exhibits in a most conspicuous manner both of these qualities. Wind is nothing more than air in motion. An example, therefore, of the effects of the power of the wind is a proof of the inertia of air. In a windmill, the moving force of all the heavier parts of the machinery proceeds from the momentum of the wind acting on the sails. A ship is propelled through the deep, and the deep itself is agitated and raised into waves, by the inertia of the atmosphere in motion. As the velocity of the air is augmented, its force becomes almost irresistible; and we find buildings totter, trees torn from their roots, and even the solid earth itself yield before the force of the hurricane.

209. **Examples.** —When the atmosphere is calm and free from wind, a solid body presenting a broad surface moved against it must drive before it and put in motion those parts of the air which lie in its way. If the air had no inertia, it would require no force to impart this motion to it; but universal experience proves that the force encountered by a body moving through the air is great in proportion to the magnitude of the surface which encounters the air, and to the speed with which it is moved. Open an umbrella and endeavour to carry it along swiftly, with the concave side presented forwards, and you immediately encounter a great resistance. This force is nothing more than what is necessary to push the air before it. On the deck of a steam-boat propelled with considerable speed, or on the top of a railway carriage, we feel on the calmest day a

breeze in a direction contrary to that in which we are moved. This arises from the sensation produced by the surface of our body displacing the air as we are carried through it.

It is the inertia of the atmosphere which gives effect to the wings of birds. Were it possible for a bird to live without respiration, and in a space void of air, it would no longer have the power of flight. The plumage of the wings, being spread and acting with a broad surface on the atmosphere beneath them, is resisted by the inertia of the atmosphere, so that the air forms a fulcrum, as it were, on which the bird rises by the leverage of its wings. The wings of birds are larger in proportion to their bodies than the fins of fishes, because the fluid on which they act is less dense, and has, proportionally, less inertia than the water upon which the fins of fishes act.

210. **Air compressible.**—In this quality it is distinguished from liquids. It has been shown that liquids are practically incompressible; for although, as a philosophical fact, a mass of liquid may, by the action of an extreme force of compression, be diminished in a very minute degree in its volume, it does not possess the quality of compressibility in the same manner in which it is manifested in aeriform bodies. If air be included in a cylinder in which a piston moves air-tight, the piston, being urged downwards by any force, will compress the air into smaller dimensions, and there is no practical limit to this compression: if the force that urges the piston be doubled or tripled, the air, as will be hereafter proved, will be reduced to one half or one third of its dimensions.

When a diving-bell is sunk to a considerable depth in the sea, the water which enters its mouth, though it cannot displace the air, compresses it, and rises to a certain height within the bell, the air giving way to it, and being condensed into a smaller space.

211. **Air elastic.**—This is another quality which distinguishes aeriform bodies from liquids. If a liquid be deposited in a cylinder under a piston, it will remain there, its surface maintaining the same position to whatever height the piston may be raised above it; but if air be contained in a cylinder, under a piston which moves air-tight, on raising the piston the air will expand, so as still to fill the augmented space below the piston; and this expansion will continue to whatever height the piston may be raised, and to whatever extent the space be augmented, in which the air is free to circulate.

It is evident that this tendency to enlarge its volume, and which is expressed by the term elasticity, will cause the air confined in any vessel to press on the inner surface of such vessel with a force corresponding to its tendency to expand. If no corresponding

ternal pressure act upon the surface of such vessel, the air will ve a tendency to burst it, and will, in fact, burst it, if it have not ength to resist the elastic force. We are enabled, by means ich will be explained hereafter, to remove the atmosphere from ound an inflated bladder. On doing this, the elasticity of the air luded in the bladder, being unresisted by any external pressure, l burst the bladder, if it have not a strength corresponding to :h elasticity.

112. **Air has weight.** — Means will be explained hereafter by ich air can be withdrawn from the interior of any vessel which ıtains it, in the same manner exactly as water can be pumped m a well. The instrument by which this is accomplished is led an *air-pump*. Let a copper or glass flask A (*fig.* 141.), ding about two quarts, having a narrow neck, provided with a p-cock B, be hooked to the dish of a balance, the stop-cock ng open, and consequently the flask filled with air, and let it be ıctly counterpoised by weights in the other dish. Let the flask

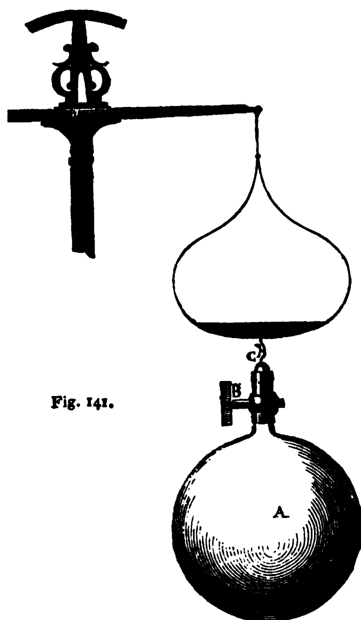


Fig. 141.

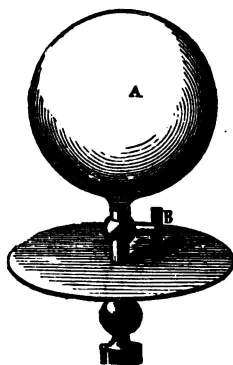


Fig. 142.

now detached from the balance; and being screwed upon the te of an air-pump, as shown in *fig.* 142., let the air be extracted

from it, and let it be again hooked upon the balance, *fig.* 141. The weight which before equilibrated with it will now decidedly preponderate; and, to restore the equilibrium, it will be necessary to put a certain amount of weight in the dish from which the flask is suspended, which may be conveniently done by pouring sand into the dish. The weight of the sand which thus restores the equilibrium will be exactly equal to the weight of the air which has been extracted from the flask.

CHAP. II.

COMPRESSIBILITY, ELASTICITY, AND WEIGHT OF AIR.

213. **Mariotte's law.** — It has been explained, in general, that when air is submitted to the action of any compressing force, it will be reduced in its volume. It remains now to investigate in what proportion its volume will be diminished by any given increase of the force which compresses it.

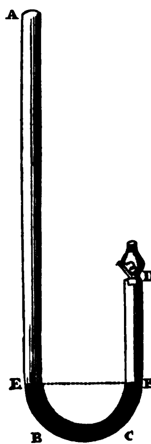


Fig. 143.

It was shown by Mariotte that the diminution of volume will be in the exact proportion of the compressing force. If the compressing force be doubled, the air which is compressed will be reduced to half its volume; if the compressing force be increased in a threefold proportion, the volume of the air compressed will be diminished in a threefold proportion, and so on. This is generally called Mariotte's law.

Let A B C D (*fig.* 143.) be a glass tube, curved at one end, B C, and having a short leg C D, with a stop-cock at its extremity D. Let the leg A B be more than 6 feet in length. The stop-cock D being opened, so as to allow free communication with the air, and the mouth of the longer leg A being also open, let so much mercury be poured into the tube as will fill the curved part B C, and rise to a small height in each leg. The surfaces E and F will then, according to the principles already explained, stand at the same level. Let the stop-cock D be now closed, so that the air in the leg D F shall be shut off from communication with the external atmosphere.

The surfaces E F will still remain at the same level.

They are, however, now acted upon by different forces; the surface E is acted upon by the weight of the atmosphere transmitted through the open tube A E But the weight of the atmosphere does not act upon the surface F, inasmuch as the stop-cock D is closed, and all communication with the external air intercepted. The surface of the mercury at F is therefore acted on only by the elasticity of the air inclosed in the tube D F; and since the surfaces E and F, under these circumstances, continue at the same level, it follows that the weight of the atmosphere acting at E is equal to the elasticity of the atmosphere manifested by the air inclosed in D F.

The method of ascertaining the actual force with which the atmosphere presses by its weight on the surface of the mercury at E will be explained hereafter. For the present it is necessary for us to assume that this force is equal to the weight of a column of mercury about 30 inches in height. We will assume, therefore, that the elastic force of the air inclosed between F and D is such that it presses upon the surface F with the same force as a column of mercury 30 inches in height would press upon it.

Now, if we pour into the tube A E as much mercury as will raise the surface in the leg A B 30 inches above the surface of the mercury in the leg D C, we shall have an additional pressure equal to the weight of a column of 30 inches of mercury transmitted from the leg A B to the surface of the mercury in the leg D F, and therefore acting as a compressing force on the air included in the leg D F. If this be done, it will be found that the surface of the mercury in the leg D F will rise so as to force the air included in D F into half its original volume, that is to say, from F to F′ (*fig.* 144.), because the level of the mercury will, when the additional column has been introduced into A E, be raised to the point F′, exactly midway between D and F, and the air which originally filled the space D F will be now compressed into one half the space, that is to say, into D F′.

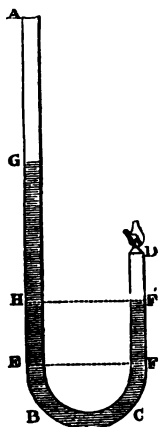


Fig. 144.

In the same manner, if mercury be again poured into the tube A E until the surface of the column in A E be 60 inches above the level of the mercury in D F, then the air in D F will be compressed into one third of its original volume.

In the former case, when the column in A E was 30 inches above the column in D F, the air was compressed by a force equal to the weight of 60 inches of mercury, because, as has been already

explained, it was compressed by the atmosphere with a force equal to 30 inches of mercury, and by the additional force of the column of 30 inches of mercury introduced into the tube. In the latter case, the air is compressed by a force equal to 90 inches of mercury, as it is compressed first by the atmosphere, equal to 30 inches of mercury, and, secondly, by the column of 60 inches of mercury introduced into the tube. The compressing forces, therefore, in the three cases, are represented respectively by 30, 60, and 90 inches of mercury; and, consequently, the compressing force in the one case is twofold, and in the other case threefold, the force by which the air is compressed in its natural state. In the same manner, to whatever extent such experiments may be continued, it will be found that the diminution of volume will always be in the exact proportion of the increase of the compressing force, and, in like manner, the augmentation of volume will be in the proportion of the diminution of the compressing force.

214. The discovery of the weight of the thin transparent fluid which surrounds the earth, which by respiration supports animal life, and is necessary to the due exercise of the animal and vegetable functions, forms a remarkable epoch in the history of physical science. The ancient philosophers observed that in the instances which fell under their notice space was filled by some material substance. The moment a solid or a liquid was by any means removed, the surrounding air instantly rushed in and filled the space so deserted. Hence they adopted the physical dogma, that nature abhors a vacuum, — a figurative proposition, meant as a statement that it was a law of nature that space could not exist unoccupied by matter.

If a tube be immersed in a liquid, and the suction of the lips be applied at the upper end, the water which surrounds it will rise in the tube as the air is withdrawn by suction. This was explained by declaring that nature abhorred a vacuum, and, therefore, the water necessarily filled the space deserted by the air.

This alleged antipathy of nature to a vacuum served the purpose of Natural Philosophy for 2000 years.

215. The question as to the cause of the elevation of water in pumps having been raised by the result of some engineering operations executed at Florence during the life of Galileo, and not having been satisfactorily explained, Torricelli, his most distinguished pupil, after the death of the master, directed his attention to its solution. He argued, that whatever be the cause which sustains a column of water in a pump, the measure of the power thus manifested must be the weight of the column of water sustained; and, consequently, if another liquid were used, heavier, bulk for bulk, than water, the same force would sustain a column

of that liquid, having less height in proportion as its weight would be greater. By using a heavier liquid, therefore, such as mercury, for example, the column sustained would be much shorter, and the experiment would be more manageable. The weight of mercury being bulk for bulk about 13½ times that of water, it followed that, if the force imputed to a vacuum could sustain 34 feet of water, it would necessarily sustain 13½ times less, or about 30 inches, of mercury. Torricelli therefore made the following experiment, which has since become so memorable in the history of physical science.

He procured a glass tube (*fig.* 145.) more than 30 inches long,

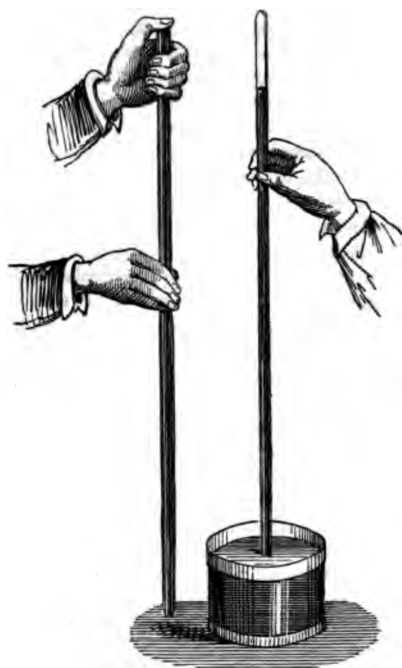


Fig. 145.

open at one end and closed at the other. Filling this tube with mercury, and applying his finger at the open end, so as to prevent its escape, he inverted it, plunging the end into mercury contained in a cistern.

On removing the finger, he observed that the mercury in the tube fell, but did not fall altogether into the cistern; it only subsided until its surface was at a height of about 30 inches above the surface of the mercury in the cistern.

This result, which was precisely what Torricelli had anticipated, clearly demonstrated the absurdity of the statement imputed to Galileo, that nature's abhorrence of a vacuum extended to the height of 32 feet, since in this case her abhorrence was limited to 30 inches. In fine, Torricelli soon perceived the true cause of this phenomenon.

The weight of the atmosphere, acting upon the surface of the mercury in the cistern, supports the liquid in the tube. But the surface of the mercury in the tube, being excluded from contact with the atmosphere, is free from the pressure of its weight; the column, therefore, of mercury being pressed upwards by the weight of the atmosphere, and not being pressed downwards by any other force, would stand in equilibrium.

This explanation was further confirmed by the fact, that on admitting the air to the upper end of the tube by breaking off the glass at that point, or opening a stop-cock placed there, the column of mercury in the tube instantly dropped into the cistern. This was precisely the effect which ought to ensue, inasmuch as the admission of the pressure of air upon the column balanced the pressure on the surface in the cistern, and there was no longer any force to sustain a column of mercury in the tube, and consequently it fell into the cistern.

216. **Pascal's experimentum crucis.** — This experiment and its explanation excited, at the epoch we refer to, the greatest sensation throughout the scientific world, and, like all new discoveries which have a tendency to explode long-established doctrines, was rejected by the majority of scientific men. The celebrated Pascal, who flourished at that epoch, however, had the sagacity to perceive the force of Torricelli's reasoning, and proposed to submit his experiment to a test which must put an end to all further question about it. "If," said Pascal, "it be really the weight of the atmosphere under which we live that supports the column of mercury in Torricelli's tube, we shall find, by transporting this tube upwards in the atmosphere, that in proportion as it leaves below it more and more of the air, and has consequently less and less above it, there will be a less column sustained in the tube, inasmuch as the weight of the air above the tube, which is declared by Torricelli to be the force which sustains it, will be diminished by the increased elevation of the tube."

Pascal therefore caused Torricelli's tube to be carried to the top

of a lofty mountain, called the Puy-de-dome, in Auvergne, and the height of the column to be correctly noted during the ascent. It was found, in conformity with the principle announced by Torricelli, that the column gradually diminished in height as the elevation to which the instrument was carried increased. The experiment being repeated upon a high tower in Paris with like success, there no longer remained any doubt of the fact, that the column of mercury in the tube, as well as the column of water in common pumps, is sustained, not by the force vulgarly called suction, nor by nature's abhorrence of a vacuum, but simply by the weight of the incumbent air acting in one case on the surface of the mercury in the cistern, and in the other on the surface of the water in the well in which the pump terminates.

The instrument which we have here described as used in the experiment of Torricelli, is nothing more than the common barometer. By the principle explained in (2.), the height of the column sustained by the atmospheric pressure will be the same whatever be the bore of the tube. If we suppose the section of the bore to be equal to one square inch, the column of mercury sustained in the tube will be balanced by the weight of a column of the atmosphere pressing upon a square inch of the surface of the mercury in the cistern. If we suppose, on the other hand, the tube to have a bore equal to half a square inch, then the atmospheric column which balances the mercury will have a base of half a square inch also.

217. **Construction of a barometer.** — In adapting such an apparatus to indicate minute changes in the pressure of the atmosphere, there are several provisions to be made.

The height to be measured being that of the surface of the column in the tube above the surface of the mercury in the cistern, it is not enough to ascertain the position of the surface in the tube, unless the surface in the cistern have a fixed level. Now it is evident that, whenever the surface in the tube rises, the surface in the cistern must fall, and *vice versâ*, inasmuch as whatever mercury enters the tube must leave the cistern, and whatever flows from the tube must return to the cistern. If the magnitude of the surface in the cistern be very considerable compared with the bore of the tube, and if extreme accuracy be not necessary, the effects arising from this cause will be too minute to need any correction; but if that extreme accuracy is desired, which is necessary in barometers used for philosophical experiments, then means must be provided of keeping the mercury in the cistern at a fixed level, or of measuring the change of level.

In *fig.* 146. the cistern A B is represented having an index at P, showing the point at which the level of the mercury in the cistern should stand. A screw is presented at V, by turning which the bottom can be elevated or depressed, so that when the level in the cistern falls it may be raised, or when it rises it may be lowered, and thus the level may always be adjusted so as to correspond with the point of the index. The scale represented at D E is divided with reference to the level determined by the point of the index P.

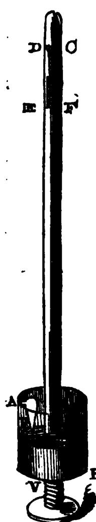


Fig. 146.

218. It is necessary that the mercury should be perfectly pure, since otherwise a column of a given height would vary in its weight, according to the quantity and quality of the impurities which the liquid might contain.

The solid impurities which mercury may contain are usually removed by straining it through chamois leather, the quicksilver passing freely through its pores, while the solid impurities are retained.

Mercury, like water, commonly contains combined with it more or less air or other elastic fluids. If such mercury were used for the barometer tube, this fixed air, when relieved from the pressure of the atmosphere, as it would necessarily be in the tube, would become disengaged, and would rise to the upper part of the tube D C, and there exert a pressure which would counteract, to a greater or less extent, the pressure of the atmosphere.

Independently of the impurities, whether of an aeriform or a liquid species, which may be combined with the mercury, the tube itself, before it is filled, is liable to be coated with like impurities. Thus particles of air and of moisture will always adhere to the inner surface of it; and even though the mercury were pure, this air and film of moisture would have a tendency, when relieved from the pressure of the atmosphere, to rise and vitiate the vacuum at the top of the barometric column.

These effects are avoided by the following expedients. The mercury, before it is poured into the tube, is boiled, in which process all the air it contains is expelled by its increased elasticity, and all the liquid impurities by evaporation. The tube itself is heated over a spirit-lamp, so that all the moisture as well as the particles of air adhering to its surface are expelled; in fine, when the tube has been filled with mercury, the mercury is boiled in it.

219. But supposing the mercury to be perfectly pure, and all

the provisions made which are necessary to indicate the exact height of the columns sustained, two barometers, equally well constructed, would still differ in their indications, if they are exposed to different temperatures. It will be shown hereafter that mercury, like all other fluids, is subject to a change of density or specific gravity with every change of temperature. If, therefore, two barometers, equally well constructed, be used in different and distant places, where they are exposed to different temperatures, the same pressure of the atmosphere will sustain columns of different heights, that which is exposed to the higher temperature being more elevated than that which is exposed to the lower. In comparing, therefore, the indications of barometers in different places, it is necessary to observe the temperature; and tables and formulæ are supplied in physical science, by which the effects of different temperatures can be ascertained, and the necessary corrections applied.

The changes incidental to the atmospheric pressure, the indication of which is the chief use of the barometer, are so limited and minute, that, owing to the great specific gravity of mercury, they produce extremely minute changes in the barometric column, which are therefore difficult to be observed.

220. **Water barometer.** — More sensible indications would be obtained by adopting a barometer of a lighter fluid than mercury. Thus, water is 13½ times lighter than mercury, and, consequently, a water barometer would exhibit a column 13½ times greater than that of mercury.

Such a column would, therefore, measure about 34 feet, and a change which would produce a variation of about the tenth of an inch in the column of mercury, would produce a variation of an inch and a third in the column of water.

But to the use of water, or any other liquid save mercury, for barometric purposes, there are numerous and insuperable practical objections. Independently of the unwieldy height of the column, which would render it impossible to transport the barometer from place to place, all the lighter liquids would produce vapour in the upper part of the tube, which would vitiate the vacuum, would react against the barometric column, and disturb its indications. The consequence of this has been, that mercury has been invariably retained as the only practicable fluid for barometers.

Several expedients, however, have been adopted in barometers used for common domestic purposes to render their indications more sensible. Although these are inapplicable in barometers used for scientific purposes, yet, as they are frequently adopted in domestic barometers, it may be useful here to notice them.

221. Diagonal and wheel barometers.—A form of barometer, called the diagonal barometer, is represented in *fig.* 147. In this the upper end of the tube is bent, so that the scale, instead of being limited to the length C D, is extended over the greater length C B.

A form of barometer, called the wheel barometer, is represented in *fig.* 148. In this, the tube, instead of having a cistern, is con-

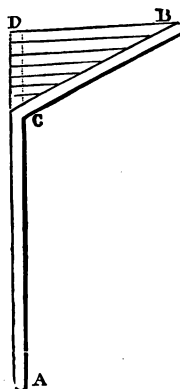


Fig. 147.

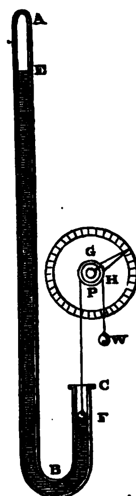


Fig. 148.

tinued of the same diameter, having its lower end bent upwards at B C. A float is placed upon the mercury at F, which rises and falls with it. The change of altitude of the level F corresponds with that of E, and the difference between the two levels E and F is the height of the barometric column. The changes of this height are always double the change of level of the surface B F. The float F is connected by a string with a wheel H, which carries an index that plays upon a graduated dial-plate G. In this manner the magnitude of the graduated scale may be made to bear any proportion, however great, to the change of level of the mercury at E, so that the smallest change of the barometric column will produce a considerable motion of the index.

The form in which this barometer is usually mounted is shown in *fig.* 149.



Fig. 149.

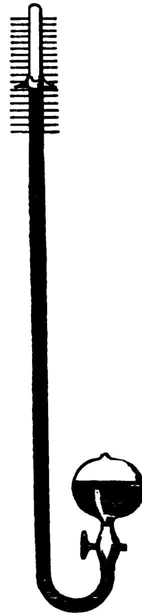


Fig. 150.

222. **Standard vertical barometer.** — One of the most common forms of this instrument is represented in *fig.* 150. The lower part of the tube, being bent into the form of a siphon, like the wheel barometer, is inserted in the lower part of an iron stop-cock, the upper part of which is inserted in a small globular cistern containing the mercury. When the stop-cock is open the column in the tube is subject to the pressure of the atmosphere acting on the mercury in the cistern. If the tube be inclined so that the mercury shall fill the top of it, and the stop-cock be then closed, the instrument may be transported from place to place without risk of air entering the tube, or other derangement. The dia-

meter of the globular cistern bears so great a proportion to that of the tube, that a rise or fall of the mercury in the tube, within the usual limits of barometric variation, produces a very inconsiderable variation in the level of the mercury in the cistern, or if greater accuracy be desired, the scale attached to the tube may be so divided as to measure, not the actual variation of the level of the column in the tube, but its variations relatively to that of the mercury in the cistern. Thus, if the diameter of the cistern be four times the diameter of the tube, the area of its section will be sixteen times that of the tube, and when the level of the mercury in the tube falls through an inch, the level of the mercury in the cistern rises through the sixteenth of an inch, so that the real decrease of the mercurial column is only fifteen sixteenths of an inch. It is evident that, if it be desired, the scale may be so divided that an actual fall of an inch may be marked as one sixteenth less than an inch, and so of other variations.

In barometers for domestic use this extreme precision is not necessary, and is so much the less so, as the most important indications of the barometer are those which depend on the *variation* of the height of the column, and not on its absolute height.

223. The gravity of air, combined with its elasticity and compressibility, supplies the means of determining, by reasoning alone, the constitution of the superior strata of the atmosphere, which are inaccessible to direct experiment

If we suppose the atmosphere, which extends from the surface of the earth upwards to a height more or less considerable, to consist of a series of layers or strata, placed one above the other, it is evident that each successive stratum, in ascending, will sustain a weight less than those below it. The first stratum of atmosphere which is in immediate contact with the surface of the earth is compressed by the entire weight of the atmosphere above it, that is to say, by the weight of the whole atmosphere, except the first stratum; the next stratum is compressed by the weight of the whole atmosphere, except that of the first two strata; the third stratum is compressed by the weight of the whole atmosphere, except the first three strata; and so on. Now, it has been already shown that the density of air is always proportional to the force which compresses it; and it follows, therefore, that the density of the first, or lowest stratum, is greater than the density of the second, and the density of the second greater than the density of the third, and so on; the air becoming gradually less dense as it ascends to a greater height.

224. **Height of atmosphere limited.** — It may be asked, under such circumstances, whether the atmosphere must not extend to an unlimited height, because, if its rarefaction augments

in proportion as the compression diminishes, there can be no limit to such rarefaction.

But it must be remembered that the constituent particles or ultimate molecules of the air itself have definite weight, and that, so soon as the rarefaction becomes so great that the elastic force proceeding from the mutual repulsion of the particles of air is equal to the weight of these particles, no further rarefaction can take place. We may therefore conceive the particles of air at the upper surface of the atmosphere resting in equilibrium, under the influence of two opposite forces, viz., their own weight tending to carry them downwards, and the mutual repulsion of the particles which constitutes the elasticity of the air tending to drive them upwards.

If a particle of air were raised above this height by the application of any external agency, and then disengaged, it would drop by its gravity to the surface of the atmosphere, in the same manner and by the same law which makes a stone drop to the ground. The limit, therefore, of the altitude of the atmosphere is that point where the rarefaction will diminish the elastic force of the air, so as to render it equal to the proper gravity of its constituent particles.

225. **Average pressure of atmosphere.** — We have seen that the height of the column of mercury which balances the atmospheric pressure at the surface of the earth is about 30 inches. Now two cubic inches of mercury weigh in round numbers a pound avoirdupois; consequently it follows, that a column of mercury, whose base is a square inch and whose height is 30 inches, will weigh 15 lbs.

But since such a column measures the pressure of the atmosphere, it follows that the atmosphere presses with a force of 15 lbs. for every square inch of surface upon which it rests.

But the air possesses, in common with all other fluids, the faculty of transmitting pressure equally in every direction; consequently it follows, that every object exposed to the atmosphere is pressed upon every part of its surface with a force amounting to 15 lbs. per square inch.

The surface of a human body of average size measures about 2000 square inches. Such a body, therefore, sustains a pressure from the atmosphere amounting to 30000 lbs., or very nearly 15 tons.

226. **Method of measuring heights by barometer.** — It has been shown that when a barometer is carried upwards in the atmosphere, the column of mercury in the tube falls, because the force which sustains it is diminished by an amount equal to the weight of the column which it leaves below it. By comparing,

therefore, the height of the column in the barometer at any two stations, one of which is above the other, we can ascertain directly the weight of a column of atmosphere extending from the lower to the higher station. Thus, for example, if the column of mercury in the barometer at the lower station be 30 inches, and at the higher station 20 inches, it follows that a column of air whose base is at the lower station, and whose summit is at the higher station, will have a weight equal to that of a column of mercury 10 inches high, and therefore that the quantity of air composing such a column will be one third of the quantity composing a column extending from the lower station to the summit of the atmosphere.

If the atmosphere were uniformly dense, the barometer would supply a most easy and simple means of determining its actual height.

In the example just given, the column of air between the two stations would weigh one third of the weight of a column extending from the lower station to the summit of the atmosphere; and, if the air were uniformly dense, it would follow, therefore, that the entire height of the atmosphere would be just three times the height of the upper above the lower station. But, owing to the circumstances already explained, which produce a gradual rarefaction of the air as the height increases, it follows that the heights of columns of air are not proportional to their weights.

If the only cause which produces a gradual rarefaction of the air as we ascend in the atmosphere were that which has been just stated, namely, the weight of the incumbent air, it would not be difficult to find a rule by which a change of altitude might be inferred from observing the change of pressure indicated by a barometer. But the temperatures of the air at the two stations of which the difference of level is sought, enter into the solution of the problem as well as the difference of the barometric columns, and the method of calculation from these data involves principles of the higher mathematics, which could not be rendered intelligible here. We may, nevertheless, give the formula which will enable any observer by the ordinary process of arithmetic to ascertain the difference of elevation of two stations.

Let H express in feet the height of the upper, and h that of the lower station above the level of the sea.

$H-h$ will, therefore, express in feet the height of the upper above that of the lower station.

Let T express the number of thermometric degrees above the freezing point, shown by the thermometer at the higher, and t at the lower station.

Let B be the height of the barometer at the higher, and b at the lower station.

Then the difference of levels of the two stations may be calculated in feet, by the following formula: —

$$H-h=60345{\cdot}7\times\{1+0{\cdot}002837\cos 2\,\text{lat}\}\times\left\{1+\frac{T+t}{900}\right\}\times\log\frac{B}{b}.$$

If the height do not much exceed 3000 feet, the following more simple formula may be used: —

$$H-h=52494{\cdot}3\times\frac{B-b}{B+b}\times\left\{1+\frac{T+t}{900}\right\}.$$

227. The barometer in the balloon in which the celebrated De Luc made his scientific voyage, fell at the greatest altitude to 12 inches. Supposing the barometer at the surface to have stood at that time at 30 inches, it follows from this, that he must have left below him in quantity exactly three fifths of the entire atmosphere, since 12 inches would be only two fifths of the complete column sustained in the barometric tube. His elevation at this moment was estimated to have been 20000 feet; but it is certain that he had not attained a point amounting to more than a small fraction of the entire altitude of the atmosphere.

Since the density of air is proportional to its pressure, other things being the same, it would follow that the density of the air in which the balloon floated on this occasion was only four tenths of the density at the surface.

Now when the barometer is at 30 inches, air is 10800 times lighter than mercury; and consequently the air surrounding De Luc's balloon must have been 27000 times lighter, bulk for bulk, than mercury. The height, therefore, of air above the balloon, supposing its density to be undiminished in rising, would have been 27000 feet, and in this case the entire height of the atmosphere would be nearly 50000 feet. But here it is to be considered, as in the former case, that in rising above the level of the balloon the air would constantly diminish in density; and consequently a column supporting 12 inches of mercury would have a much greater elevation than 27000 feet.

228. **Fortin's portable barometer.** — When the barometer is used under any of the circumstances described in the preceding paragraphs, it is necessary that it should be portable, and also that the difference of the levels of the mercury in the cistern and in the tube should be capable of being observed with the greatest precision. Various forms of barometer have accordingly been contrived so as to fulfil these conditions, one of the best of which is that of Fortin, represented in *fig.* 151.

The instrument is mounted on a jointed tripod, which serves as a case for it when it is not in use. The bottom of the cistern is formed of a flexible membrane not penetrable by the mercury.

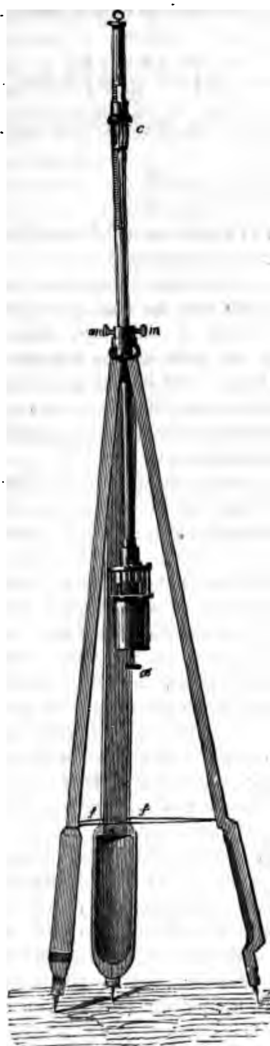


Fig. 151.



Fig. 152.

This membrane is
upon a small piece,
is supported by a
the milled head of
is at *a*, under the c
By turning the scr
way or the othe
piece to which it
tached can be rai
lowered, and the l
the mercury in th
tern will sustain
responding change
this adjustment th
cury in the cistern,
ever an observat
made, is raised o
ered until its sur
brought into conta
the point of the
index *b* (*fig.*
which shows the
on a larger scale.
adjustment is ma
looking at the s
of the mercury th
the side of the
cistern, and obs
the inverted ima
the ivory index
flected in it. Th
cury is raised b
screw, until the p
the index and that
image come into c

To determine th
sition of the surf
the mercury in th
there is a sliding
c, which has two
ings cut on o
sides of it, the ed
which are horizont
precisely at the
level when the tube is vertical. The observer, looking th

the two openings until these edges are brought into the line of sight, moves the sliding piece *c*, until that line becomes a tangent to the convex surface of the mercury in the tube. Upon the sliding piece is engraved a vernier scale, which enables the observer to ascertain the true height of the mercurial column, subject to no greater error than the 250th part of an inch.

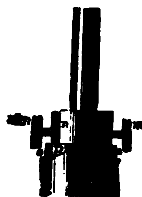


Fig. 153.

The precision of the indications of this instrument would be sensibly disturbed, if the mercurial column were not truly vertical; for, in fact, to whatever extent it might be inclined to the vertical, it would become a diagonal barometer.

To ensure its vertical position, a method of suspension is provided, represented on a larger scale in *fig.* 153., which consists of two small screws *m m*, by which the tube is fixed firmly in a sort of glove *n*. Two small trunnions adapted to this glove form an axis, on which the barometer can swing in one direction. These trunnions are supported in two openings of a ring *p*, which can itself turn freely upon two other trunnions *q*, placed at right angles to the former. The instrument is therefore supported, and capable of oscillating at the same time on two horizontal axles perpendicular to each other; a mode of suspension similar precisely to that of a ship's compass, which, as every one may have observed, has its card always horizontal, and its axis vertical, however much the ship may pitch or roll.

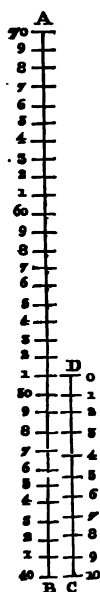


Fig. 154.

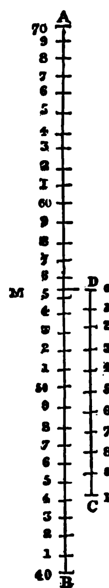


Fig. 155.

229. **Use of the vernier.** — The sliding scale called a vernier, to which we have alluded above, is applied to all forms of vertical barometer. The vernier is a contrivance which, by a subsidiary scale, supplies the means of estimating small fractions of the smallest division marked on the principal scale.

Let A B (*fig.* 154.) represent a part of the principal scale. Let C D be the sliding scale or vernier, which we will suppose to consist of 10 divisions, equal in their total length to 11 divisions of the principal scale. Each division of the vernier will therefore be equal to eleven tenths of a division

of the chief scale, and will exceed a division of the chief scale by a tenth of a division.

Let us suppose that the index D of the vernier (which coincides with its zero) stands, as in *fig.* 155., at M, between the divisions marked 55. and 56., and that the question is to estimate how much it is above 55. Observe what division of the scale coincides, either exactly or most nearly, with a division of the vernier. The number of the vernier which stands at such division of the scale will express the number of tenths of a division of the chief scale between the index of the vernier and the 55th division of the chief scale. In the present case the 4th division of the vernier coincides nearly with the 51st division of the chief scale. The point on the chief scale indicated, therefore, by the vernier, is 55·4.

It is evident that the distance from the 55th division of the chief scale to the point M, which coincides with the index or zero of the vernier, is the difference between 4 divisions of the vernier and 4 divisions of the chief scale; and since a division of the vernier exceeds a division of the scale by a tenth, 4 divisions of the vernier exceed 4 of the scale by four tenths.

230. **Extreme variations incidental to the barometer.** — The physical effect of which the barometric column is the measure is the weight of the atmosphere at the place where this barometric column is situated; and consequently the variations, whatever they may be, which are incidental to the column, indicate corresponding variations in the weight of the atmosphere. Now it has been found that the barometric column is subject to two species of variation: one of an extremely minute amount, and which takes place at regular periods; the other of much greater amount, and which may be considered as comparatively contingent and accidental. The extreme limit of this latter variation is, however, not great. The greatest height, for example, which the barometer kept at the Paris Observatory has been known to attain is 30·7 inches, and the lowest 28·2 inches, the difference being 2·5 inches, or $\frac{1}{12}$th of the average height of the column.

The mean height of the barometer at Paris, obtained from observations continued for several years, has been found to be 29·77 inches.

231. **Diurnal variation.** — The periodical variations of the barometric column are extremely complicated, though very minute. In winter it is found that the column attains a maximum height at nine in the morning; it falls from this hour until three in the afternoon; it then begins to rise, and attains another maximum at nine in the evening. In summer the hour of the first maximum is eight in the morning, and that of the minimum four in the

afternoon; that of the second maximum being eleven at night. In spring and autumn this maximum and minimum take place at intermediate hours.

232. **Supposed connection between barometric changes and the weather.** — The accidental variations of the barometer, or, to speak more properly, those which are not periodic, and which are much greater in magnitude, have been generally supposed to be prognostics of change in the weather, and hence the barometer is sometimes called a weather-glass. Rules have been attempted to be established by which, from the absolute height of the mercurial column, the coming state of the weather may be predicted; and we accordingly find the words Rain, Fair, Changeable, Frost, &c. engraved upon the scale attached to common domestic barometers, as if, when the mercury stands at the heights marked respectively by these words, the weather were always subject to the vicissitudes expressed by them.

It requires but little reflection on what has been stated to show the fallacy of such indications. The absolute height of the mercurial column varies with the position of the instrument. A barometer in Fleet Street will be higher at the same moment than one on the top of St. Paul's, and consequently two such barometers would indicate different coming changes of the weather, though absolutely situate in the same place. Two barometers, one of which is placed at the level of the Thames, and the other at the top of Hampstead Hill, will differ by half an inch, and consequently would indicate, according to the usual scales, different coming changes.

Fallacy of the popular rules. — It is evident, therefore, that the absolute height of the barometer cannot in itself be an indication of anything but the weight of the atmosphere in the place where the instrument stands, and the words engraved on barometric plates which have just been referred to are altogether unworthy of serious attention.

Nevertheless, at a given place the column varies between certain limits, usually from 2¼ to 2½ inches; and when the mercury is at its highest limit, the prevailing character of the weather is fair; when at its lowest, it is rainy and stormy; while at the intermediate altitude it is variable.

Different meteorological observers have attempted to embody and generalise the results of their observations in a collection of rules, by which the weather may be prognosticated. The following brief general maxims have been proposed: —

I. Generally the rising of the mercury indicates the approach of fair weather, the falling of it shows the approach of foul weather.

II. In sultry weather, the fall of the mercury indicates coming

thunder. In winter the rise of the mercury indicates frost. In frost its fall indicates thaw, and its rise indicates snow.

III. Whatever change of weather suddenly follows a change in the barometer, may be expected to last but a short time. Thus, if fair weather follow immediately the rise of the mercury, there will be very little of it; and, in the same way, if foul weather follow the fall of the mercury, it will last but a short time.

IV. If fair weather continue for several days, during which the mercury continually falls, a long succession of foul weather will probably ensue; and again, if foul weather continue for several days while the mercury continually rises, a long succession of fair weather will probably succeed.

V. A fluctuating and unsettled state in the mercurial column indicates changeable weather.

Here is another set of barometric weather prognostics:—

I. If the barometer begin to fall slowly and steadily after a long continuance of dry weather, rain will certainly follow; but if the fair weather have been of very long duration, no perceptible change may take place for some days, and the longer the time which elapses between the fall of the barometer and the commencement of the rain, the longer will be the subsequent continuance of the foul weather.

II. The preceding rule may be inverted. If the barometer begin to rise slowly and steadily, after a long continuance of rainy weather, fair weather will certainly follow; and if several days elapse between the rise of the barometer and its commencement, it will have so much the longer continuance.

III. If, in either of these cases, the changes follow promptly upon the motion of the mercury, the new state of the weather will not be of long continuance.

IV. If, during two or three days successively, the barometer rise slowly and steadily, rain nevertheless falling constantly, fair weather will certainly follow, and *vice versâ*. But if the barometer rise during rain, and then fall at the commencement of fair weather, the fair weather will be very transient, and *vice versâ*.

V. A sudden fall of the mercury in spring or autumn is followed by high winds; in summer, and especially during sultry weather, it is followed by a thunder-storm. In winter, a sudden fall after long-continued frost, is followed by a change of wind, and a thaw and rain; but after a continued frost, a rise of the mercury is usually followed by snow.

VI. No rapid fluctuations of the mercury are to be taken as indications of any change of long continuance. It is only the slow, steady, and continuous rise or fall that is to be attended to as such a prognostic.

VII. A rise of the mercury late in the autumn, after a long continuance of wet and windy weather, generally indicates a change of wind towards the north, and approaching frost.

233. **Height of homogeneous atmosphere.** — The weight of mercury is 13½ times greater than that of water, and the weight of water is about 800 times that of air, at the mean density of the latter; consequently, the weight of mercury is, bulk for bulk, 10800 times greater than the weight of air; therefore a column of air of uniform density, equal in weight to the barometric column, would be 10800 times higher. Now, taking the average height of the barometric column at 2½ feet, a column of air of equal weight, and having a uniform density equal to that of air at the surface of the earth, would give a height of 27000 feet; and, since the barometric column is subject to irregular variations, which range within a twelfth of its entire height, the corresponding column of air would be subject to like variations, ranging within a like proportion of its entire height, which, according to this calculation, would amount to 2250 feet. If, therefore, the atmosphere were, like the ocean, of uniform density, the height of the waves, which would be incidental to its surface agitated by the disturbances to which it is exposed, would be nearly half a mile.

Enormous height of atmospheric waves. — But as the atmosphere is not of uniform density, but diminishes in density in a rapid proportion as the height increases, its altitude is much greater than 27000 feet; and the change incidental to its superficial level indicated by the variations of the barometer must be proportionally greater. The waves of the sea, therefore, even in the most violent storms, are absolutely insignificant compared with the waves which prevail in the upper surface of the ocean of atmosphere under which we live.

234. It might be expected that the great pressure to which all bodies surrounded by the atmosphere are exposed would produce conspicuous effects, in crushing, compressing, or bursting them; whereas it is found that even the most delicate textures are not affected by it. A bag made of the lightest and finest tissue partially filled with air, is practically subject to no external pressure; its sides, though loaded with an enormous pressure, do not collapse. This is explained partly by the equality of the pressure which is directed upon it on all sides, and partly by the resistance produced from within, by the elasticity of the air contained in it.

The same circumstances explain the fact that animals are neither obstructed in their movements, nor crushed by the enormous pressure to which their bodies are subjected. The atmosphere pressing them equally in every possible direction, laterally and obliquely, upwards and downwards, has no tendency to impel them in any

one direction rather than another, and consequently offers no other resistance to their motion than is produced by the inertia of the atmosphere itself. The internal pores of their bodies being filled with fluids, both liquid and gaseous, producing a pressure outwards exactly equal to the external pressure of the air inwards, an equilibrium results, and no part of the body is crushed.

The effect of the internal fluids in resisting the external pressure of the atmosphere may be rendered manifest by applying an exhausting syringe or a cupping-glass to any part of the skin. Such an instrument has no other effect than that of removing the atmospheric pressure from that part of the surface to which it is applied; but when it does this, immediately the skin is distended and sucked, as it were, into the glass, in consequence of the elasticity of the fluids contained in the organs.

235. The various phenomena, which are vulgarly called suction, are merely the effects of atmospheric pressure. If a piece of moist leather be placed in close contact with any heavy body having a smooth surface, such as a stone or a piece of metal, it will adhere to it; and if a cord be attached to the leather, the stone or metal may be raised by it.

This effect arises from the exclusion of the air between the leather and the stone. The weight of the atmosphere presses their surfaces together with a force amounting to 15 lbs. on a square inch of the surface of contact.

236. The power of flies, and other insects, to walk on ceilings, smooth pieces of wood, and other similar surfaces, in doing which the gravity of their bodies appears to have no effect, is explained upon the same principle. Their feet are provided with an apparatus similar exactly to the leather applied to the stone.

237. **Experimental proof of the crushing force of the atmosphere.** — That the air in the inside of vessels is the force which neutralises the great pressure of the external air, may be shown by the following experiment: —

A strong glass vessel is provided, open both at top and bottom, and having a diameter of four or five inches. Upon one end is tied a bladder, so as to be completely air-tight (*fig.* 156.). The other end is placed upon the plate of an air-pump, being previously smeared with lard, to make the contact air-tight. The air under the bladder is rarefied by the operation of the pump, and the bladder is subject to a pressure from without, proportional to the difference between the pressure of the external air and the pressure of the rarefied air under the bladder. When the rarefaction has been car-



Fig. 156.

ried to such an extent that the strength of the bladder is less than this pressure, the bladder bursts with a loud report.

238. **The Magdeburg hemispheres.** — The great force of the atmospheric pressure is also shown in a striking manner by the apparatus thus denominated. It consists of two hollow brass hemispheres (*fig.* 157.) with evenly ground edges, which admit of being brought into air-tight contact when smeared with lard. The apparatus when secured upon the plate of an air pump may be exhausted, so that the space within the hemispheres may be rendered a partial vacuum. The external air will thus press the two hemispheres together with a force proportional to the difference between the pressure of the external air and the pressure of the rarefied air within. When a sufficient exhaustion has been produced, the stop-cock attached to the lower hemisphere is closed, the apparatus is unscrewed from the pump-plate, and a handle screwed upon the lower hemisphere. It will be found that two of the strongest men will be unable to tear the hemispheres asunder, provided they are of a moderate magnitude, owing to the amount of the pressure with which they are held together. If, for example, the pressure of the rarefied air within is equivalent to a column of two inches of mercury, while the external air has a pressure represented by 30 inches of mercury, there will be a force amounting to 14 lbs. per square inch in the section of the hemispheres.



Fig. 157.

If the hemisphere have 4 inches diameter, the area of their section will be $12\frac{1}{2}$ square inches, and consequently the force with which they will be pressed together will be

$$12\tfrac{1}{2} \times 14 = 175 \text{ lbs.}$$

This apparatus derives its name from the place where the inventor of the air pump, Otto Guericke, first exhibited the experiment, in the year 1654. The section of the hemispheres employed by him measured 113 square inches, and they were held together by a force equal to about three-fourths of a ton.

239. **Influence of air upon apparent weight.** — Air being proved to have weight, and the property of transmitting pressure freely in all directions, all the properties which solid bodies have been shown to manifest when they are immersed in liquids, will be equally applicable, *mutatis mutandis*, to solids immersed in or surrounded by air. Thus, as the apparent weight of a solid immersed in a liquid is less than its real weight by the weight of the

liquid it displaces, the same solid surrounded by air will have an apparent weight less than its real weight by the weight of the air it displaces. The only difference between the two cases is that in the case of liquids, the weight of the fluid displaced always bears a considerable proportion to that of the solid; but in the case of air, owing to its comparatively small specific gravity, the weight displaced is so insignificant compared with that of the solid, that except under peculiar and exceptional conditions, it may be altogether disregarded.

It may, nevertheless, be shown that in cases where the bulk of a solid is considerable compared with its weight, its buoyancy, caused by the air surrounding it, produces a sensible effect upon its apparent weight.

Thus, for example, let two extremely thin balls of glass (*fig.* 158.) be suspended to the arms of a balance, and let them be brought to equilibrium, by adding the necessary weight to one or the other; let the balance, with the balls suspended to it, be then placed under the receiver of an air pump, and upon exhausting the air, it will be found that the equilibrium is no longer maintained, and that the larger ball will preponderate. This is easily explained: the apparent weights which produce equilibrium in the air, are the real weights diminished by the weight of the air displaced, and consequently the larger ball suffers a greater diminution of weight than the smaller. When the air is withdrawn, this unequal diminution being removed, the greater ball gains more weight than the lesser, and preponderates.

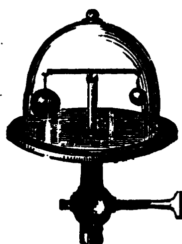


Fig. 158.

240. **Resistance of air.**—Since air possesses inertia, it offers, like liquids, a resistance to any body which passes through it, and this resistance, for the same reason as in the case of liquids, increases as the square of the velocity of the moving body, other things being the same.

The force with which air in motion strikes a solid body is the same as the resistance which the solid body would encounter from the air if it moved against it at the same speed.

How great the force is which is produced in such cases by the collision of air with solid bodies, is proved by the effects which air produces in storms and hurricanes.

Since the resistance of the air to the motion of a body increases as the square of the velocity, it will follow that a body falling through the air suffers a rapidly increasing resistance, and that when such resistance becomes equal to its weight, which it always

will do if the fall be sufficiently continuous, the body will no longer be accelerated, but will descend to the ground with a uniform velocity.

In a series of experiments which I made several years ago for some of the railway companies in England, with a view to determine the rate of increase of resistance to railway trains depending on the air, I found that a train descending an inclined plane soon acquired a velocity which suffered no farther increase, and was continued to the foot of the plane with the most perfect uniformity.

I caused a locomotive engine, placed behind an experimental train, on the summit level above an inclined plane, to impel the train with a velocity of more than 45 miles an hour to the summit, and thence to dismiss it down the plane. The motion of the train was accurately observed in passing a series of equidistant stakes, planted along the side of the road. It was found that the train, instead of being accelerated, was retarded, and that this retardation continued until the speed was reduced to about 32 miles an hour, which was then maintained uniformly to the foot of the plane.

It follows, therefore, in this case, that the atmospheric resistance, at 32 miles an hour, added to the friction of the wheels, was equal to the total weight of the train resolved in the direction of the plane.

241. **Velocity of the wind.—Anemometers.**—Instruments by which the velocity of the wind can be measured have received the name of *anemometers*, from the Greek word *ανεμος* (*anemos*), wind. These have been constructed in a great variety of forms, one of which is similar in principle to the instrument of Mr. Woltmann for measuring the velocity of the currents of rivers, shown in *fig.* 88.

In the following table are given approximate values of the velocity of the air, which produces winds of the different forces there indicated:—

	Feet per second.		Feet per second.
Wind barely sensible - - -	3·5	Very strong wind - - - -	50·
Feeble wind - - - - - -	7·	A violent wind - - - - -	70·
Fresh breeze sufficient to fill sails -	20·	Tempest - - - - - - -	100·
Wind sufficie tly strong to drive a windmill - - - - - -	25·	Hurricane - - - - - - -	120·
Fresh breeze at sea - - - - -	25·	A storm sufficient to overturn buildings - - - - - - -	160·
Wind sufficient to double reef topsails	40·		

242. **Air balloons.**—If a solid body, bulk for bulk, be lighter than air, it will ascend in the atmosphere upon the same principle as that by which a cork rises to the surface in water.

If a hollow vessel of sufficient magnitude could be exhausted by an air pump, and if it could be constructed with sufficient strength

to resist the external pressure of the atmosphere, and at the same time so light that its entire weight would be less than the weight of the air extracted from it by the pump, such a body would necessarily rise in the atmosphere, its weight being less than that of the air it displaces. But these conditions are impracticable; there is no material of which such a body could be constructed, so as to be at the same time sufficiently light and sufficiently strong.

If a fluid could be found lighter, bulk for bulk, than air having the same pressure, then a hollow vessel filled with such a fluid would be subject to no external pressure tending to crush it, and might be lighter, bulk for bulk, than air, and under such circumstances it would ascend in the atmosphere.

243. The first attempts to realise these conditions were by means of heated air. When air is heated it expands, and, bulk for bulk, becomes lighter than it is at a lower temperature.

If, then, a large bag, composed of paper or silk, or other light material, be filled with heated air, the weight of such a bag, including its contents, might be less than its own bulk of air in the natural state, and it would consequently have a buoyancy proportional to such difference of weight.

244. The application of this principle formed the first successful attempt in aerostation. In the year 1782, the celebrated Montgolfier, residing at Annonai, made a series of experiments which ultimately terminated in the formation of a balloon of the spherical form, containing 23000 cubic feet of heated air, and having such a buoyancy as to be capable of raising a gross weight of 500 lbs. This machine rose in the atmosphere to the height of 6000 feet. In this, and subsequent similar experiments, the air within the balloon was kept heated by a fire which was lighted below it, the balloon having an open mouth at its lowest point, through which the flame of the fire was transmitted.

After the first successful experiment, in which the balloon alone was made to ascend, persons were found having sufficient courage and enterprise to attempt an ascent by such means in the atmosphere. The first persons who attempted and successfully accomplished this, were M. Pilâtre des Roziers and the Marquis d'Arlandes. Their balloon, magnificently decorated, as shown in *fig*. 159., was terminated below by a circular gallery for the accommodation of the aeronauts. A grate suspended within it was placed within their reach, so that they could during the voyage feed the fire in it with straw, a supply of which they brought with them, so as to sustain the rarefaction necessary to give the balloon sufficient buoyancy.

This memorable experiment was made without accident, on the

21st of November, 1783, from the garden of La Muette, at Passy, near Paris.

245. The step from the fire balloon to balloons filled with gas, lighter, bulk for bulk, than the atmosphere, was easy and obvious. The gas denominated hydrogen was no sooner discovered than it was applied to this purpose.



Fig. 159.

This gas, being about seven times lighter than atmospheric air, has considerable buoyancy; balloons, accordingly, filled with it, would rise to a great height in the atmosphere.

It has been already explained that as we ascend in the atmosphere, the strata of air have less and less density: a balloon, therefore, containing gas whose pressure balances the lower strata, will, if it be completely filled, have a tendency to burst when it ascends into the rarer strata; for the gas, not having room to expand, will

maintain its original elastic force, while the atmospheric pressure, being diminished in the ascent, will cease to balance it. There will therefore be a bursting pressure equivalent to the excess of the atmospheric pressure at the lower strata, over the pressure in the superior strata to which the balloon ascends.

These effects are prevented practically by inflating, only imperfectly, the balloon at the moment of its ascent. When it rises into the superior strata, the gas accordingly expands, and the balloon becomes comparatively filled, gaining at the same time increased buoyancy by the increased expansion of the gas within it. If it ascend to a still greater height than that at which the inflation becomes complete, it is relieved from the bursting force by means of a safety valve.

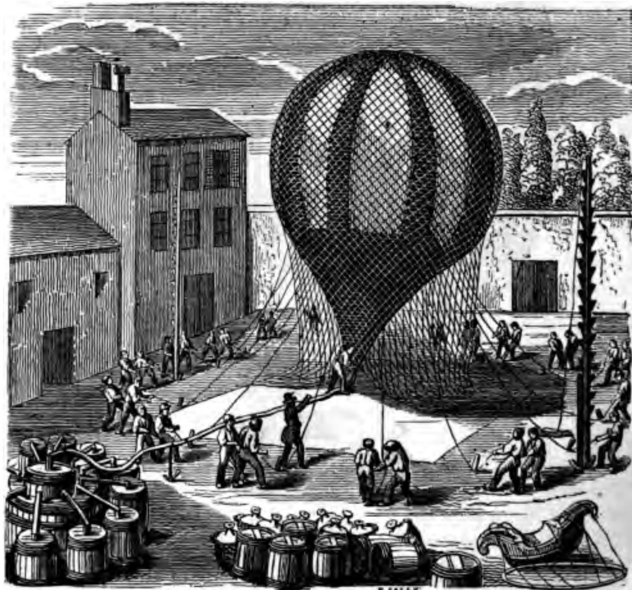


Fig. 160.

When the aeronaut desires to descend, he is provided with a valve, by which he can discharge a part of the gas, so as to diminish the buoyancy of the balloon; and when he requires to ascend, he is provided with ballast composed of sand-bags, by casting out which he diminishes the weight of the balloon.

Before the introduction of gas-lighting, the process of inflating a balloon consisted in the production of the necessary volume of hydrogen gas by a chemical process. The oil of vitriol being mixed in a small proportion with water, and a quantity of sheet zinc, or zinc filings, or iron filings, being thrown into the liquid, a chemical action takes place, in which the water is decomposed. It is well known that water is a chemical combination of the two gases, oxygen and hydrogen. The presence of the vitriol or sulphuric acid, causes the zinc or iron to attract the oxygen of the water, and to form with it an oxyde, while the hydrogen, the other component of water, is liberated.

In the process of filling a balloon, a great number of casks or other vessels containing the acid solution and the metal were provided, and the hydrogen, as it was evolved, was conducted to the mouth of the balloon, as shown in *fig.* 160.

Since the general introduction of gas for the purposes of illumination, the inflation of balloons has become much more easy and economical. The gas used for illumination is a species called carburetted hydrogen: it is a little heavier than pure hydrogen, and, consequently, gives a little less buoyancy than that gas; but it gives sufficient for all the purposes of aerostation.

Wherever gas-works exist, a balloon can be inflated with this gas by merely connecting it by a flexible pipe with a gas main.

The first successful experiment made with a hydrogen balloon took place in the Champ de Mars, near Paris, on the 22nd of August, 1783, and on the 1st of December following, Messrs. Charles and Robert ascended personally, and conducted the experiment without accident.



Fig. 161.

The usual form of the hydrogen balloon, with its car, is shown in *fig.* 161.

246. The impracticability of governing balloons in their course through the air has prevented, and probably will continue to prevent, them from being applied to any purpose of permanent or extensive utility. Scientific voyages have, however, been made into the atmosphere with some success, for the purpose of observing, at great elevations, meteorological phenomena. In 1804, MM. Gay Lussac and Biot made an ascent from Paris, taking with them meteorological apparatus, and attained a height of 13000

feet. Soon afterwards, M. Gay Lussac ascended alone to a height of 23000 feet; and a like elevation has recently been attained by MM. Barral and Bixio.

247. In 1807 M. Garnerin made a nocturnal ascent, and, rising with unusual rapidity, attained a prodigious elevation. By some neglect, the apparatus for discharging the gas became unmanageable, and the aeronaut was obliged to make an incision in the balloon, which then descended with such rapidity that he was obliged to counteract its motion, by casting out his ballast. The balloon, in this way, alternately rose and sunk for eight hours, during which he experienced the phenomena of a thunder-storm, by which, in fine, he was driven against the mountains, and landed at Mont Tonnerre, a distance of 300 miles from the place of his ascent.

248. Attempts have been made to render balloons useful in military operations. A captive balloon is held attached to a cord of sufficient length, so that a person can ascend to a corresponding height and obtain a bird's-eye view of the enemy's movements. An academy for the practice of this manœuvre was formerly established at Meudon, near Paris, where a corps of aeronauts was trained. The project, however, was soon abandoned.

249. **Parachutes.** — It has been shown that the resistance of



Fig. 162.



Fig. 163.

the air soon stops the acceleration of a falling body. Even a cannon ball let fall from a sufficient height, would, after a certain

time, cease to be accelerated. The major limit of the velocity of the descent would obviously depend upon the weight of the descending body, and the extent of the surface it presented to the air. If the weight be sufficiently small, and the resisting surface sufficiently great, the velocity of the descent may be reduced to a very small amount.

An expedient called *parachutes*, by which an aeronaut is enabled to let himself fall to the earth with impunity, has been constructed upon this principle, and consists, as shown in *fig.* 162., of an umbrella of vast dimensions, to the handle of which a light basket to support the aeronaut is suspended. When the parachute is first disengaged, the umbrella is folded up, as shown in *fig.* 162., and the fall is extremely rapid. But the air, soon entering the folds, makes them expand and take the form shown in *fig.* 163., when the descent is rapidly retarded. This retardation is continually increased as the aeronaut approaches the ground, owing to the increased density of the air.

250. **Aerial navigation.** — This problem has engaged the attention of a certain class of projectors more remarkable for sanguine temperament than for scientific attainment.

That the problem, considered abstractedly, is possible, cannot be doubted. Birds navigate the air by means of a propelling apparatus with which nature has supplied them; and Icarus, relying upon this analogy, made wings, attempted to fly, and encountered a failure, which has formed the theme of poets.

The solution of the problem of aerial navigation involves three objects, two of which have been successfully attained: 1st, to rise in the atmosphere; 2nd, to move through it in any desired direction; and 3rd, to descend from it. The first has been accomplished by the balloon, and the third also by the balloon, as well as by the parachute. The second, however, has never been accomplished.

The magnitude which the balloon must necessarily have to give it sufficient ascensional force is so considerable as to oppose an enormous resistance to its motion through the air, and any propelling apparatus must necessarily exert a force greatly exceeding this resistance. To obtain such a force, it must act upon the air by surfaces of considerable magnitude moved with great velocity. In whatever manner such an apparatus may be constructed, it must have a weight bearing some proportion to its propelling power; and as it must be carried up by the balloon, it would render necessary a proportionately increased ascensional power, which could only be obtained by a proportionately increased volume, and this would be attended with an increased resistance from the air.

By a due consideration of these general principles, it will become evident that even were it practicable to construct a propelling instrument light enough to be carried up by a balloon, the resistance of the air, even in a dead calm, would be such that the rate of progress to be obtained from it would be altogether inconsiderable.

But the slightest acquaintance with atmospheric phenomena will render it apparent that a dead calm is a rare and exceptional state of the air. A wind always prevails, and especially in the superior strata of the atmosphere, and in general its velocity would bear an almost infinite proportion to any velocity which could be impressed on the balloon by any propelling apparatus. The utmost possible effect of such an apparatus would therefore be, to cause the balloon to follow a course inclined, probably, at considerably less than half a degree to the direction of the wind.

We may therefore safely infer, that notwithstanding the wonderful results which have been attained by discoveries in physics applied to the arts of life, there is but little ground for expecting a successful practical solution of the problem of aerial navigation.

251. **Kites.** — A kite is sustained in the air by the equilibrium of three forces: 1st, that component of the wind which acts perpendicular to its surface, and which is directed obliquely upwards; 2nd, its own weight, which is directed vertically downwards; and 3rd, the tension of the string, which is directed obliquely downwards. When the kite has assumed such position and height that the first of these three forces is equal, and directly opposed to the resultant of the second and third, the kite will be stationary. If the first be greater than that resultant, the kite will ascend; if less, it will descend.

252. **The air-gun.** — The air-gun is an instrument by which balls or other missiles are projected by the elastic force of compressed air, instead of the expansive force of gunpowder.

A strong hollow chamber, usually having the form of a metallic sphere, is provided, into which air is driven by means of a condensing syringe. This is screwed upon the gun near the breach, so as to communicate with the interior of the barrel behind the ball, the pipe of communication being governed by a valve or cock, which is connected with the trigger. On drawing the trigger, the valve is opened, and the barrel put in free communication with the condensed air, which, pressing behind the ball, propels it towards the mouth, from which it is projected with a corresponding force. The stock of the gun may contain a supply of balls, and be furnished with a simple mechanism, by which they may be succes-

sively transferred to the barrel, so that the gun may be immediately loaded after each discharge.

253. Let a glass be completely filled with water (*fig.* 164.), and a leaf of paper be so applied to its mouth as to exclude the air, and let the palm of one hand be applied upon it, while the glass is inverted with the other hand. The hand applied to the paper may then be withdrawn; and although the mouth of the glass is presented downwards, the water will not be discharged from it, being supported in it by the pressure of the atmosphere acting on the paper.



Fig. 164.



Fig. 165.

Let a glass be plunged in a vessel of water (*fig.* 165.), and, when all the air has been expelled from it, and it is filled with water, let it be raised with its mouth downwards, until the edge of its mouth shall be only a small depth below the surface of the water. It will continue to be completely filled with water, the liquid being sustained in it by the pressure of the atmosphere upon the water in the vessel.

254. **Gasometers.** — This name is somewhat improperly given to large cylindrical reservoirs in which gas is collected, in gas-works, for general distribution. These reservoirs act upon the principle here explained; they consist, as shown in *fig.* 166., of a large cylindrical reservoir suspended with its mouth downwards, and plunged in a cistern of water of somewhat greater diameter. A pipe which leads from the gas-works is carried through the water, and turned upwards, so as to enter the mouth of the gasometer. The gas, flowing through this pipe, rises into the gasometer, filling the upper part of it, and pressing down the

water. Another pipe, descending from the gasometer through the water, is continued to the gas main, to which it supplies the gas. The gasometer is balanced by counter weights supported by chains, which pass over pulleys, and just such a preponderance is allowed to it as is sufficient to give the gas contained in it the compression necessary to drive it through the pipes to the remotest part of the district to be illuminated.

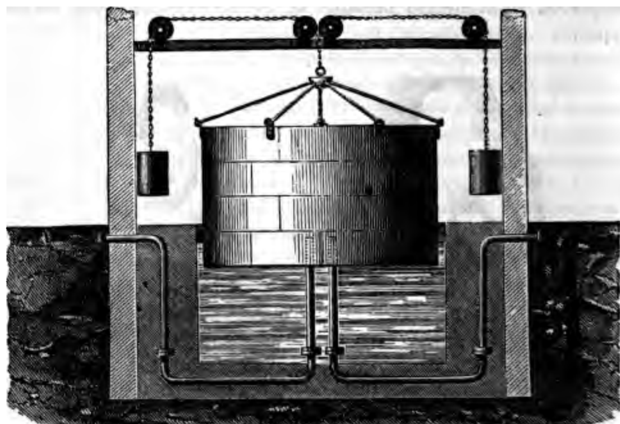


Fig. 166.

255. **The diving-bell.** — This machine depends for its effect on the impenetrability which air enjoys in common with all material substances. The diving-bell is a large vessel closed at the sides and top, but open at the bottom, impenetrable to air and water. When pressed with its mouth downwards into the water, the water partially enters the mouth, compressing the air within it. As it descends, this compression increases; and at a depth of thirty-four feet, being equal to that of the atmosphere, the air included in the bell will be compressed into half its volume, and consequently the bell will be half filled with water. Apparatus is provided by which this effect is counteracted, by forcing in air by means of a condenser worked at the surface, communicating by a pipe which descends and enters the bell by being brought under its mouth. It is forced in until the water is brought nearly to the mouth of the bell, which is thus filled with air in a compressed state.

According as the air included in the bell is rendered impure by respiration, it is discharged, and fresh air is received by means of the condenser and pipe just mentioned. Strong glass lenses, similar to those fixed in the deck of a ship, are set in the top of the bell, by which light is admitted to the interior. The shape of the machine is generally oblong, with seats for the divers, shelves for writing materials and other articles being placed at the sides. Messages are communicated from the bell to the surface above, either by writing or by signals. A board is carried in the bell, on which a written message may be chalked, and which is connected by a cord with the superintendent above.

When the bell is of cast iron, signals are given by striking it with a hammer, which produces a sound distinctly audible at the surface of the water. The bell is usually suspended by a crane placed at the surface of the water, so that its position can be changed within certain limits. Means, however, are also provided by which the divers can emerge from the bell, and move about in the water, having dresses by which they are enabled to respire the air included in the bell.

256. **Action of bellows.** — When the boards A B (*fig.* 167.) of the bellows are separated, the inner chamber C is enlarged, and the air is forced in by the external pressure through the aperture D, governed by the leather valve or clack. The boards being then pressed together, and the escape of the air being stopped by the closed valve, it is compressed until it acquires an elasticity greater than the atmospheric pressure, and is forced out.

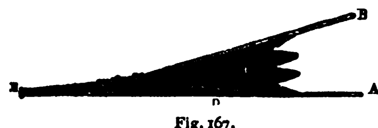


Fig. 167.

Bellows on a large scale are constructed with an intermediate board B (*fig.* 168.), so as to consist of two chambers, F and C, and to produce a continued instead of an intermitting blast. This is nothing more than a double bellows, one, C, forcing air into the chamber of the other, F, and the second being urged by an uninterrupted pressure, produced usually by a weight suspended from the upper board.

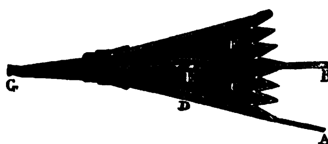


Fig. 168.

257. **Vent-peg.— Lid of teapot.** — The effect produced by a vent-peg in a cask of liquid is explained by the atmospheric

pressure. The cask being air-tight, so long as the vent-peg is maintained in its position, the surface of the liquid in the vessel will be excluded from the atmospheric pressure, and it can only flow from the cock in virtue of its own weight. If the weight of the atmosphere be greater than the weight of a column of the liquid, corresponding with the depth of the liquid in the vessel, the liquid cannot flow from the cask; but the moment the vent-peg is removed, the atmospheric pressure being admitted above the level of the liquid in the cask, the liquid flows from the cock in virtue of its own weight.

If the lid of a teapot or kettle were perfectly close, the liquid would not flow from the pipe, because the atmospheric pressure would be excluded from the inner surface. A small hole is therefore usually made in the lid to admit the air and allow the liquid to flow freely.

258. **Pneumatic ink-bottle.** — Ink-bottles are sometimes so constructed as to prevent the inconvenience of the ink thickening and drying. Such a bottle, represented in *fig.* 169., is a close glass vessel, from the bottom of which a short tube proceeds, the depth of which is sufficient for the immersion of a pen. When ink is poured in at C, the bottle, being placed in an inclined position, is gradually filled to A. If the bottle be now placed in the posisition represented in the figure, the chamber A being filled with the liquid, the air will be excluded from it; and the pressure, tending to force the ink upwards in the short tube C, will be equal to the weight of the column of ink, the height of which is equal to the depth of the ink in the bottle A, and the bore of which is equal to the section of the tube C. The ink will be prevented from rising in the tube C by the atmospheric pressure, which is much greater than the pressure of the column of liquid in the bottle. As the ink in the short tube C is consumed by use, its surface will gradually fall, a small bubble of air will then insinuate itself, and will rise to the top of the bottle A, where it will exert an elastic pressure, which will cause the surface of the ink in C to rise a little higher; and this effect will be continually repeated, until all the ink in the bottle has been used.

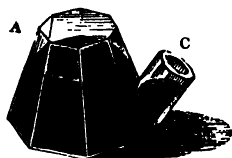


Fig. 169

Bird-cage fountains are constructed on the same principle.

The peculiar gurgling noise produced in decanting wine arises from the pressure of the atmosphere forcing air into the interior of the bottle to replace the liquid which escapes.

259. **Wine taster.**—When it is desired to draw a small sample of wine from a cask, a little instrument, represented in *fig.* 170., is used, consisting of a metal tube of the form shown in the figure, with a very small opening at the point, and a larger one at the upper end. The bung being removed from the cask, the instrument is let down into it to a small depth, when the wine will enter it at the lower orifice, expelling a portion of the air from the upper orifice. The thumb of the hand which holds the instrument being then applied firmly on the upper orifice so as to prevent air from entering, it is raised from the cask with a quantity of wine in it, which cannot escape from the lower orifice, being resisted by the atmospheric pressure. The lower orifice is then placed over the mouth of a wine glass, and the thumb is removed from the upper orifice, when the air, entering the instrument, forces the wine into the glass.

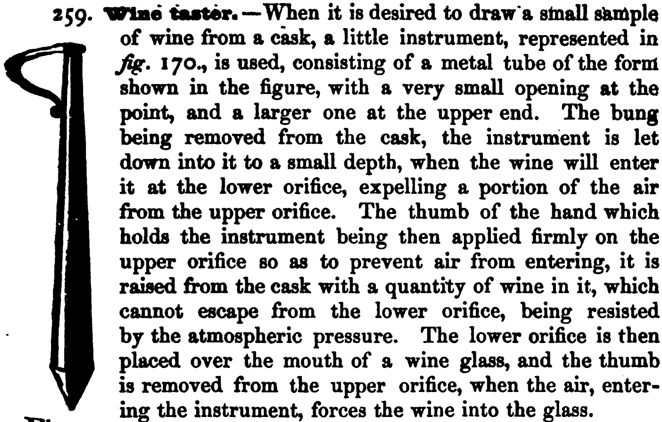


Fig. 170.

260. **Methods of maintaining a constant level.**—When the liquid contained in a vessel is diminished either by evaporation, leakage, or discharge, it is sometimes desirable that it should nevertheless be maintained always at the same level by some self-acting expedient. An elegant method of accomplishing this, used in chemical experiments, may be applied occasionally in operations on a larger scale in the industrial arts.

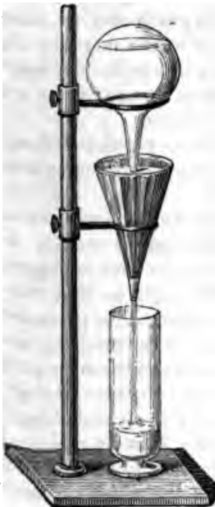


Fig. 171.

Above the vessel (*fig.* 171.), in which a constant level is to be maintained, another vessel filled with water is placed with its mouth downwards, and plunged in the water contained in the first. The atmospheric pressure, acting on the surface of the water in the lower vessel, will, in this case, prevent the water from falling out of the upper vessel. Let us suppose that the orifice of the upper vessel is placed precisely at the point where it is desired that the level of the water in the lower vessel should be maintained; and let the water in the latter flow from a small orifice at its lowest point into a third vessel placed under it. When the level of the water in the lower vessel falls in the least degree below the mouth of the upper vessel, a bubble of air will ascend in the latter, and, occupying the upper part, it will press upon the water in it, and force a small quantity

of it into the lower vessel, so as to raise the level in the latter a very little above the mouth of the former. The water still flowing from the lower vessel, the level will again fall below the mouth of the upper, and the same effects will ensue.

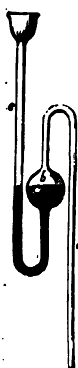


Fig. 172.

In this manner, the level of the water in the lower vessel will rise and fall alternately through an extremely small height, letting, from time to time, bubbles of air enter the upper vessel. This variation of level, however, is so inconsiderable, that for all practical purposes the level of the water in the lower vessel may be regarded as constant.

261. **Safety pipe.**—This is also a chemical expedient which may sometimes be advantageously available in the arts. In all processes where gas is evolved in a closed vessel, its pressure becoming greater than that of the atmosphere, it will have a bursting force equal to the excess. To prevent this from attaining a dangerous limit, a glass tube, called a *safety pipe*, consisting of two vertical legs *a* and *c* (*fig.* 172.), one presented downwards and the other upwards, with a recurved part, having a bulb *b* in its centre, is provided, the bulb *b* and tube *c* being partially filled with mercury, which will stand at the same level in both, so long as the tubes *a* and *c* are both exposed to the atmosphere. But if the tube *a* be inserted in the vessel in which gas is evolved, the pressure of the gas will act upon the surface of the mercury *b*, while the column in *c*, being exposed to the atmospheric pressure, will rise to a height above *b*, proportional to the excess of the pressure of the gas above that of the atmosphere.

The entire height of the tube *c*, however, is so regulated that the mercury will overflow the top of it before any dangerous pressure is acquired by the gas.

262. **Steam and gas gauge.**—In chemical experiments, and still more in all larger operations where steam or gas is used, it is necessary at all times to possess a visible indicator and measure of its force. A recurved glass tube, such as that represented in *fig.* 173., is found to serve this purpose effectually. The vertical leg *b a*, enters the reservoir of steam or gas, which, therefore, presses upon the mercury or other liquid in the bulb *b*, and forces the mercury up in the tube *c*; but as that tube is filled with air and closed at the top, the ascent of the mercury in it is resisted by the compressed air, the force of which will therefore be equal to the force of the steam or gas which presses on the mercury in *b*, added to the pressure due to the difference of the levels of the mercury in *b* and *c*. But as this



Fig. 173.

latter is always very inconsiderable compared with the pressure to be measured, that of the air compressed in *c* may be taken as equal to that of the steam or gas.

263. **Pneumatic lamp.** — In various forms of lamps the atmospheric pressure and the variations to which it is subject by more or less rarefaction plays an important part. If the surface of the oil in the reservoir be subject to the ordinary pressure of the atmosphere, it will be at the same level with that of the oil in the burner. But if, as often happens, the air in the reservoir is in a state of rarefaction, then the level of the reservoir must be above that of the burner, in order to compensate for the greater pressure upon the latter.

We have already noticed the different forms of lamps in which the mechanical properties of liquids alone have play. We shall now notice one which depends for its performance on those of elastic fluids.

In *fig.* 174 a lamp is represented, the reservoir of which is placed above the burner, with which it is connected by a bent pipe *d*. The lamp is mounted on a vertical rod, on which it slides, and can be fixed at any desired height by a tightening screw.

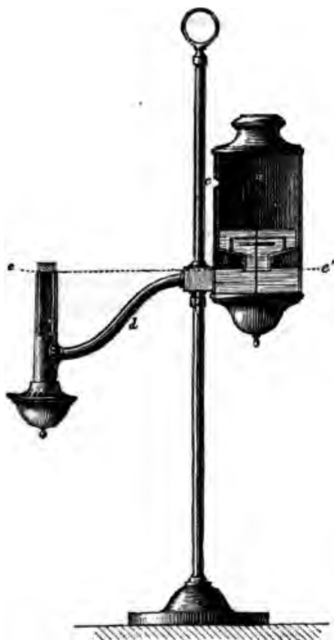


Fig. 174

The reservoir consists of two cylindrical vessels, one passing within the other like the tubes of a telescope. The outside one has its mouth upwards and cover downwards; the inside, its cover upwards and mouth downwards. The latter is shaped like a flask, being contracted at the neck, and a circular disc of metal is placed within it, having a rod attached to its centre by which the mouth is stopped when it falls upon it. This disc is prevented from entering the vessel by a bar through which its rod passes, and which is shown in *fig.* 174.

Let us suppose this flask-shaped vessel drawn out of the external cylinder, and turned with its mouth upwards, the metal disc will then fall down upon the bar, leaving the mouth open. Let it then be filled with oil, and when so filled, and the disc drawn up so as to stop the mouth, let it be inverted

and let down into the external cylinder c'. When it is let down to a certain depth, its descent is checked by a flange which surrounds its cover, and which rests upon the edge of the external cylinder, and at the same time the rod, coming against the bottom of the latter, the disc is raised, so that the oil flows out of the flask, filling the lower part of the cylinder c' to a level above the mouth of the flask. As the oil falls from the flask a it leaves a vacuum above it, or at least a space filled with air, more or less rarefied. Air being admitted freely to the external cylinder through a small hole c, the surface of the oil b b, in the external cylinder, is subject to the whole atmospheric pressure, while the oil in the flask is subject to an incomparably less pressure. The oil in the flask, therefore, will stand at a higher level than the oil in the external cylinder, the level of which will be but little above the mouth of the flask. The pipe d, and the burner which it supports, are so adjusted that the top of the burner shall correspond with the level of the oil in the external cylinder.

According as the oil is consumed in the burner, its level will fall both there and in the cylinder, but being very little above the mouth of the flask a very small descent will make it fall below the latter, when the mouth of the flask, being for a moment uncovered, a small portion of air will enter, will rise in bubbles through the oil, and will arrive at the upper part a of the flask, where it will produce an increased pressure upon the surface of the oil within, and thereby a decreased difference between the levels of the oil in the flask and in the cylinder. The oil in the latter will then again rise a little above the mouth of the flask, and the lamp will again remain in the same state, until, by the consumption of oil in the burner, the level of the oil is again brought below the mouth of the flask, more air is admitted, and the same effects ensue.

Thus it appears that in this form of lamp the level of the oil in the reservoir and burner is subject to a small fluctuation, rising and falling alternately above and below the mouth of the flask, and consequently, the state of saturation of the wick and the brilliancy of the light will be subject to a corresponding variation. When the lamp, however, is properly constructed, this variation of the level of the oil is so small that the change of intensity of the light is not perceptible.

The chief objection to this lamp, constructed as shown in the figure, is, that it casts a shadow on that side of the burner at which the reservoir is placed. It answers, however, very conveniently for reading or writing, since its elevation can be varied at pleasure, and nearly the whole of the light thrown upon the book or paper by means of a conical reflecting shade, the best material for which is paper or paste-board.

When two or more burners are connected with the same reservoir, and placed at equal distances around it, a lamp of this form may be used as a suspended lamp, in which case the inconvenience of shadows is removed. Suspended lamps in large rooms or halls, having several burners around the same reservoir, are often constructed on this principle.

CHAP. III.

RAREFACTION AND CONDENSATION OF AIR.

264. THE effects, infinitely various, produced by the atmosphere on bodies, whether organised or unorganised, cannot be made fully manifest unless we are enabled to exhibit the same objects under other atmospheric conditions, such as when exposed to an atmosphere much more rare and much more condensed. Instruments for experimental investigation have been accordingly contrived, by which the air surrounding objects of experimental inquiries can be either rarefied or condensed to any desired extent within practical limits. We shall in the present chapter explain the principal instruments by which these processes are exhibited, and give some examples of their use.

265. **The exhausting syringe.**—Let A B, *fig*. 175., represent a cylinder having a solid piston P moving air-tight in it. Let a tube proceed from its lower end, furnished with a stop-cock C, and let B be another tube furnished with a stop-cock D. Let the tube C be screwed upon any vessel such as R, from which it is desired to extract the air.

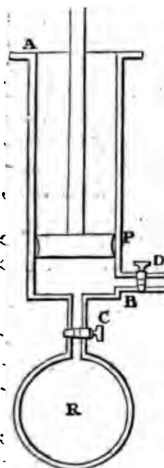


Fig. 175.

If the piston be now raised in the cylinder, the cock D being closed and the cock C being open, the air in R will necessarily expand, in virtue of its elasticity, so as to fill the enlarged space provided by raising the piston. The air which previously filled the vessel R and the connecting tube will, in fact, now fill these, and also the enlarged space in the cylinder. When the piston is brought to the top of the cylinder, let the cock C be closed and the cock D be opened. Upon driving down the piston, the air which fills the cylinder will be expelled from the tube B through the open stop-cock D. When the piston has reached the bottom of the cylinder, let D be closed and C opened, and let the same process be repeated; the air filling the vessel R will, as before, dilate itself, so as to fill that vessel and the cylinder. The cock C being again closed, and D opened, and the piston driven down, the air which fills the cylinder will be again expelled. This

process being continued, any desired quantity of air can be taken out of the vessel R and expelled into the atmosphere.

It is evident that the escape of the air from R into the cylinder is effected in virtue of its elasticity; while its escape from the stop-cock D into the atmosphere is effected in virtue of its compressibility.

266. It is easy to explain the rate at which the air is drawn from the vessel R by this process. If we suppose the volume of the cylinder through which the piston passes to be $\frac{1}{10}$th, for example, of the entire volume of the cylinder, the tube, and the connecting pipe, taken together, then it is clear that on completing the first downward stroke of the piston, $\frac{1}{10}$th of all the air included between the piston and the surface of the vessel R will be expelled, and $\frac{9}{10}$ths consequently will remain.

At every succeeding stroke, $\frac{1}{10}$th of what remained after the preceding stroke will be expelled, and in the same way $\frac{9}{10}$ths will remain.

If we suppose the vessel R and the connecting tube to contain ten million grains weight of air, in twelve strokes of the syringe something more than seven millions, or seven tenths of the whole, will be withdrawn, and something less than three tenths remain.

267. A rarefaction has been therefore produced in the proportion of something more than three to ten. But it will be apparent that although by this process the rarefaction may be continued to any required extent, a literal and absolute vacuum can never be produced; because some quantity of air, however small, must always remain in the vessel R. After every stroke of the piston, $\frac{9}{10}$ths of the air which is in the vessel before the stroke remains in it. Now it is evident that if we successively subtract $\frac{1}{10}$th of any quantity, we must always have some remainder, however long the process be continued; and the same will be true, whatever proportion be thus continually subtracted.

268. Nevertheless, although an absolute vacuum cannot be obtained by such means, we can continue the process until the rarefaction shall be carried to any required extent.

In practice, the stop-cocks D and C are replaced by valves. A valve is placed at D, which, opening outwards, is forced open by the elasticity of the air compressed under the piston when depressed, but is kept closed by the external pressure of the atmosphere when the piston is raised. The valve at C opens upwards, and is opened by the elasticity of the air in R when the piston is raised, and kept closed by the elasticity of the compressed air in the cylinder when the piston is depressed. Instead of placing a tube and valve at B, it is usual to make the valve in the piston itself, opening upwards; but the action is still the same. An exhausting syringe, therefore, may be shortly described to consist of a cylinder with two valves, one in the bottom, opening upwards,

and one in the piston, also opening upwards. When the piston is drawn upwards, the valve in the bottom of the cylinder is opened by the pressure of the air under it, and the air passes through it. When the piston is driven downwards, the valve in the piston is opened by the elasticity of the air compressed under it, which rushes through it.

269. The air pump, of which a perspective view is given in *fig.* 176., and a section in *fig.* 177., is an apparatus consisting

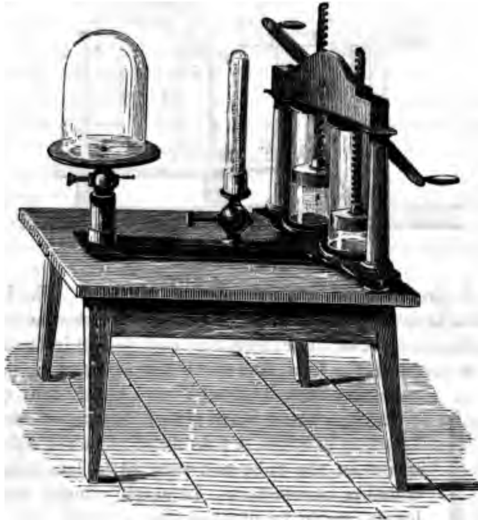


Fig. 176.

usually of two exhausting syringes, B B′ (*fig.* 177.), mounted so as to be worked by a single winch and handle, as represented at D, and communicating by a common pipe T with a glass vessel R, in which may be placed the objects of experiment. The vessel R, called a receiver, has an edge S ground smooth, resting upon a plate, also ground smooth, and kept in air-tight connection with it by being smeared with hog's lard. A stop-cock C is provided in the pipe T, by which the communications between the receiver R and the syringes can be made and broken at pleasure. Another stop-cock is provided elsewhere, by which a communication can be made at pleasure between the interior of the receiver R and the external air. To indicate the extent to which the rarefaction is carried from time to time by the operation of the syringes, a mercurial gauge H G M is provided, constructed in all respects

similar to a barometer. The atmosphere presses on the surface of the mercury in the cistern M, while the column of mercury in the

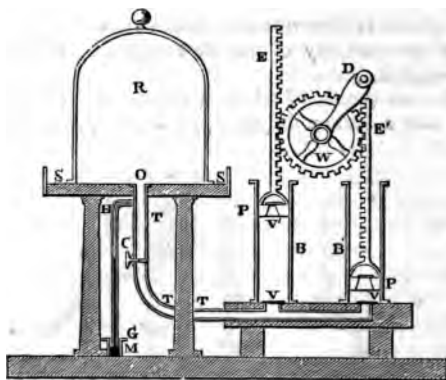


Fig. 177.

tube H G is pressed upon by the rarefied air in R. The height of the column, therefore, sustained in the tube, indicates the difference between the pressure of the external air and the air in the receiver.

When a gauge of the form represented in *fig.* 177. is used, it is necessary that it should have the height of about 30 inches, since, when a high degree of rarefaction has been effected, a column of mercury will be sustained in the tube H G very little less than in the common barometer. In small pumps, where this height would be inconvenient, a siphon-gauge, such as that represented in *fig.* 178., is used. This gauge is screwed on to a pipe communicating with the receiver. Mercury fills the leg A B, which is closed at the top A, and partially fills the leg S. When the atmosphere communicates freely with the tube D C, the surface of the mercury in S, being pressed by its full force, sustains all the mercury which the tube B A can contain, and this tube consequently remains completely filled; but when the pipe D C S is put in communication with the exhausted receiver, the surface of the mercury in S being acted upon only by the pressure of the rarefied air in the receiver, the weight of the higher column in B A will predominate, and the mercury will fall in it, until the difference of the levels in the two legs shall be equal to the pressure of the rarefied air in the receiver.

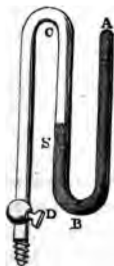


Fig. 178.

270. **The condensing syringe.** — This instrument differs from the exhausting syringe only in the direction in which the valves are placed. It consists of a cylinder and piston, as represented in *fig.* 175. When the piston is drawn upwards, the cock D is open, and C is closed, and the cylinder is filled with air proceeding from the external atmosphere. When the piston is pressed downwards, the cock D is closed, and C is opened, and the air which filled the cylinder is forced into the vessel R. On raising the piston again, the cock C is closed, and D is opened, and the effects take place as before. It is evident that, by every stroke of the piston, as much air as fills the cylinder is driven into the vessel R.

In practice, the cocks D and C are replaced by two valves, one in the bottom of the cylinder, and the other in the piston, both opening downwards, contrary to the valves in the exhausting syringe.

The operation is explained in the same manner.

271. **The condenser.** — The condenser is an apparatus which bears to the condensing syringe precisely the same relation which the air pump bears to the exhausting syringe. It consists of one or two condensing syringes, mounted so as to be conveniently worked by a winch, and communicating with a strong reservoir, which is fastened down upon a plate so as to be maintained in air-tight contact with it, notwithstanding the bursting pressure of air condensed within it. By the operation of syringes, volumes of air corresponding to their magnitude are forced continually into the reservoir, which becomes therefore filled with an atmosphere proportionally more dense than the external air.

272. **Liquids not absolutely incompressible.** — Although the theorems of hydrostatics are all established on the principle that liquids are absolutely incompressible, this must be received only in a qualified sense. It was shown, nearly a century since, by Canton, that water, when submitted to a compressing force of a certain intensity, was perceptibly compressed, and that when relieved from the pressure, it recovered its dimensions. It was evident, therefore, from this, that water, and, as it also appeared, other liquids, are not only compressible, but elastic. The degree of compression, however, produced even by the most extreme forces, is so minute, that for all practical purposes liquids may be, and are, treated as incompressible fluids.

273. **Piezometer.** — More exact experiments for determining the degree of compressibility of liquids have recently been made, first by Oersted, and still more recently by Régnault. The instrument invented and used for this purpose by Oersted was called by him a Piezometer, from two Greek words, πιέζω (piezo), *I compress*, and μετρον (metron), *a measure.*

A glass flask *a* (*fig.* 179.), tapering to a narrow neck, is connected with a glass tube of very small diameter, like the tube of a thermometer. The flask and part of the tube being filled with water, a small drop of mercury is let into the tube which rests upon the surface of the water at *b*, being prevented from sinking below its surface by reason of the very small bore of the tube. The flask, thus prepared, is placed in the bottom of a vessel A, made of thick glass, and beside it is placed a glass tube *m*, closed at the upper and opened at the lower end. The vessel A is then filled with water, which fills also the part of the tube connected with *a* which is above the mercury, but which rises only to an inconsiderable height in the tube *m*, being excluded from it by the air which it contains. In the top of the vessel A is inserted a cylinder, in which a solid piston moves, urged by a screw, which turns in a nut at *c*. Beside this cylinder is a funnel, having a stop-cock in its bottom, through which the vessel A is filled. When it is full, the stop-cock being closed, the screw is turned so as to press the piston B upon the water. This pressure is transmitted to the mercury *b* by the water in the vertical tube, and by the mercury to the water in the flask *a*. Now it is found that when the pressure on B is rendered sufficiently intense, the mercury *b* falls in the tube, so that a corresponding portion of the water which was in the tube is thus forced into the flask.

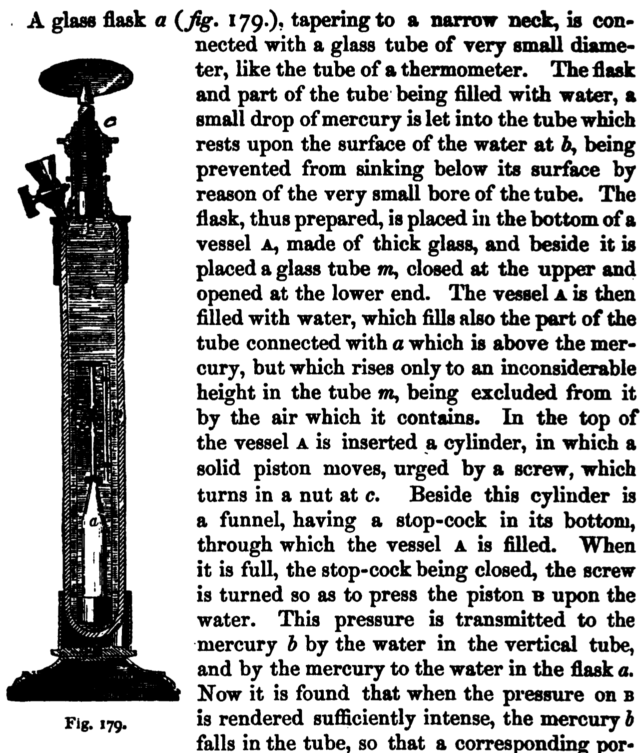


Fig. 179.

It is evident that if, under these circumstances, the capacity of the flask remain the same, it would follow that the water contained in the flask and tube under the mercury must be diminished by the volume of the tube through which the mercury has descended, and that consequently the water would have been to that extent compressed. But it might be supposed that the compression thus produced upon the water in *a*, having a tendency to distend the flask, would increase its capacity, and in that case the descent of a part of the water contained in the tube into the flask, would not arise from compression. So far, however, from this being the case, it is easy to show that instead of an increase of capacity, the flask must undergo a small but totally insensible diminution of capacity. To perceive this it is only necessary to consider that the pressure exerted by the piston B is transmitted

equally to the inside and outside surfaces of the flask *a*, and that, consequently, there is exactly as much pressure tending to force the sides of the flask inwards and to diminish its capacity, as to force them outwards, and increase its capacity. These two forces, therefore, being in equilibrium, the capacity of the flask *a* is neither increased nor diminished.

But if we push the investigation of the mechanical effects of these two pressures on the inside and outside surfaces of the flask to its extreme limits, it will follow that their tendency is to compress the two surfaces together, so as to render the glass thinner without otherwise altering the form of the flask. Though such a compression of the glass must be regarded as so infinitely minute as to have no practical existence, its effect, such as it is, would be to decrease the dimensions of the flask without in any other way changing its form or proportions. Now it is evident that such a decrease of dimension would be attended with a decrease of capacity in the proportion of the cube of the decrease of linear dimensions. Such a decrease of capacity, therefore, were it sensible at all, would cause the mercury *b* to ascend, and not to descend.

The dimensions of the bore of the vertical tube being known, the proportion which the water contained in any given portion of it bears to the entire volume of water contained in the flask and tube will be exactly known, and, consequently, the diminution of volume which the water undergoes for any given descent of the mercury *b* in the tube will be known.

But it still remains to show how the force exerted by the piston B, which produces this compression, is measured. The small air tube *m* supplies an easy and exact means of doing this: this tube being in fact such a pressure gauge as has been described above (269.).

Before any pressure is imparted to the water at A, the water is almost completely excluded from the tube *m*, and the air included in it has a pressure very little greater than that of the atmosphere. According as the pressure at B is increased, the water is forced into the tube *m*, and the air in it is compressed. When the water rises so far as to fill half the tube *m*, the pressure at B will be equal to that of the atmosphere; when it rises so as to fill two thirds of the tube *m*, the pressure at B will be twice that of the atmosphere; and so on. Thus the tube *m* becomes an indicator of the compressing force, while the tube *b* is an indicator of the extent of the pressure produced.

274. By experiments made with apparatus constructed upon such principles, it has been ascertained by M. Régnault that water, when submitted to the pressure of an atmosphere, or 15 lbs. per square inch, supplies a diminution of volume amounting to

48 parts in a million; that is to say, that a million of cubic inches of water, when subjected to a pressure of 15 lbs. per square inch, suffers a diminution of volume amounting to 48 cubic inches. If it be submitted to twice that pressure it will suffer a diminution of volume amounting to 96 cubic inches; and so on.

It was found that mercury suffered a diminution of volume of only 35 parts in 10 millions for each compressing atmosphere.

275. **Atmospheric railway.** — Until a very recent date the use of the air pump was confined to the laboratory of the philosopher, where it served the purpose of ascertaining the effects produced on various natural phenomena by the presence or absence, or greater or less rarefaction, of the surrounding atmosphere. It has recently, however, received an important application in the art of transport.

Railways worked as usual, by means of locomotive engines, must be maintained very nearly at a uniform level. Thus an acclivity which rises at the rate of not more than 1 foot in a hundred, an inclination not perceptible to the eye, presents a serious impediment to the locomotive, and an acclivity of 1 in 50 renders its use almost impracticable. When the accidents of the surface of a country render it impossible to avoid such acclivities at particular points of a line of railway, it has been found necessary to substitute for the locomotive another moving power. In most cases the object is attained by a stationary steam-engine of adequate power, which imparts motion to an endless rope carried over rollers along the whole extent of the acclivity, passing round large grooved wheels at the summit and the base. A motion of revolution is imparted to these wheels by the engine, and the rope is thereby constantly drawn up the acclivity on one side, passing down it on the other.

In certain localities, however, the winding course of the line and other causes render this method difficult, if not impracticable; and in such cases the expedient which has received the name of the *atmospheric railway* has been resorted to with success.

The principle of this moving power is easily explained. A large iron tube, so constructed as to be air-tight, is laid along the line between the rails, in which a piston or diaphragm is inserted so as to be movable in it. This piston is so contrived as to be connected with the train of carriages upon the rails above it, so that when it is moved within the tube the train receives a corresponding motion on the rails. Air pumps of vast power are erected in a convenient position at the summit of the acclivity, and are worked by stationary steam-engines. The air in the tube above the piston is thus partially exhausted, and the other side of the piston having free access to the atmosphere, a corresponding pressure is produced

upon it, by which the piston is impelled up the acclivity, drawing with it the train of carriages.

The descent of the train requires no other power than that supplied by its own gravity; on the contrary, the declivity is generally so considerable that the application of brakes is necessary to moderate the speed.

From what has been stated it will be apparent that there is nothing in the principle of this moving power to limit its application to steep inclined planes, to which, nevertheless, it has been hitherto exclusively confined. It is, in fact, equally applicable to a level or to any undulating line; but hitherto the cost of erecting and working it, and some other practical considerations, have rendered it much less convenient than the locomotive engine, or even than the stationary steam-engine and endless rope, save in the exceptional cases already mentioned.

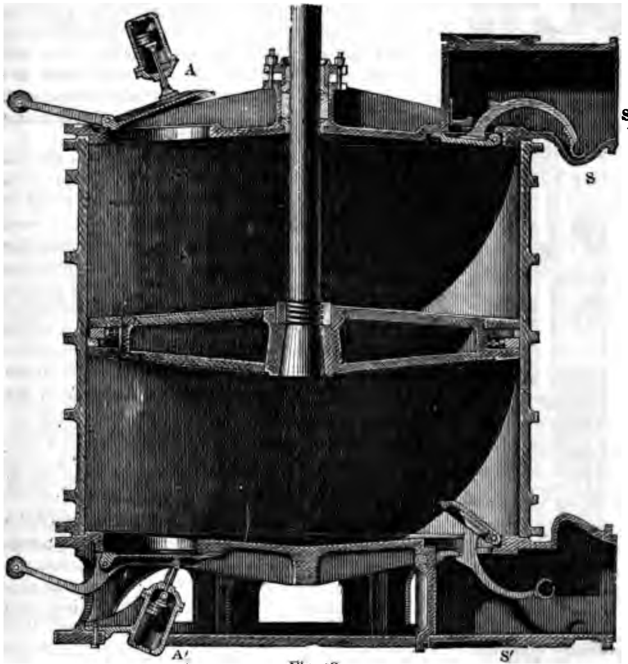


Fig. 180.

To convey some notion of the machinery by which the general principles explained above are carried into practical effect, we


Fig. 181.

shall here briefly describe the apparatus erected for working the atmospheric railway established at the St. Germain terminus of the Paris and St. Germain railway.

The great suction tube is exhausted by four enormous double-acting air pumps, the cylinder of each of which is 8 feet 10 inches in diameter. One of these cylinders is represented in section, in *fig.* 180., upon a scale of 1 inch to 3 feet 9 inches. At the top and bottom there are two valves, one opening into a pipe S, which leads to the suction pipe upon the line, and the other opening into the atmosphere. The figure represents the piston in the act of rising to the top of the cylinder. The air compressed above it raises the valve A, but keeps the valve S closed, the pressure forcing it against its seat. Meanwhile, a vacuum being produced below the piston, the atmospheric pressure keeps the valve A′ closed, while the pressure of the air in the suction pipe S′ opens the valve leading into the cylinder. When the piston reaches the top of the cylinder, the valves which were opened are closed, and for a moment all the four valves are closed, the cylinder under the piston being filled with air drawn from the suction pipe S′.

The piston now begins to descend, and the air beneath it, being compressed, soon exceeds the pressure of the atmosphere, and opens the valve A′, while it holds the valve leading into the suction pipe only more firmly closed. Meanwhile, the atmosphere keeping the valve A closed, and a vacuum being produced over the piston, the pressure of the air in the suction pipe S opens the valve leading into the cylinder; and when the piston has descended to the bottom, the air which was below it will have been expelled into the atmosphere through the valve A′, while the cylinder above the piston will have been filled by air drawn from the suction pipe S.

In the same manner each stroke of the piston draws from one or other suction pipe a quantity of air equal in volume to the cylinder, and expels an equal quantity into the atmosphere.

All that has been said in our explanation of the philosophical air pump, is applicable in the present case. But there is an important difference, inasmuch as, while the vacuum required to be produced in philosophical experiments is nearly perfect, nothing more than a slight rarefaction is required in this case.

It now remains to show in what manner the air pump impels the train.

A tube is laid along the line of railway midway between the

ong the top of which there is a longitudinal slit or opening ches in breadth, covered by a leather lid which is attached ide like a valve, and falls on the other side of the slit when t supported. A longitudinal section of this tube is repre- in *fig.* 181., showing the piston, which is impelled along it atmospheric pressure, and the apparatus by which the valve is raised so as to admit the air behind the piston.



Fig. 182.

The piston is double, a section of each part of it being shown at A and B, *fig.* 181. Each of these pistons is surrounded by a conical ring of leather, which, diverging from the edges of the pistons, applies itself to the sides of the tube. The air is partially exhausted from the part of the tube which is in front of the pistons. The valve is raised behind the pistons by the pieces F F, and is kept up by the intermediate rollers G G. The iron plate D, rising up through the slit in the tube, is attached to a waggon, which, resting upon the rails, draws the train after it. To this waggon the frame C C, supporting the pieces d the rollers G G, is thus suspended, the centre of gravity being under the waggon, by placing at E a counterpoise to the pistons. nsverse section of the tube and internal apparatus, showing the of sustaining the valve H open, is given in *fig.* 182.

Air pump for ventilating mines.—To renew the air in the working of mines it is found necessary to establish a current up one shaft and down another, which will of necessity produce a corresponding current in the intermediate workings. Let A B (*fig.* 183.), for ex- example, be a working, to which two shafts, B D and A E, communicate. When these shafts have different heights, as generally happens, the air in them having a different temperature from that of the external

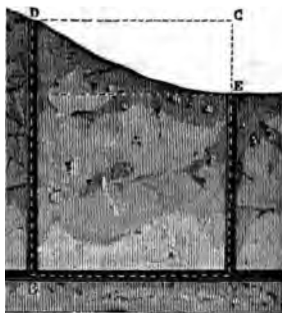


Fig. 183.

here, the density, and therefore the pressure of the column l be different from that of C E; and if the equal columns l A E be added to these, the pressures at B and A will be also l, and therefore a current will be established towards the ere the pressure is less.

Although, however, more or less ventilation is generally produced by this natural cause, the safety and health of the miners so essentially depends on a continual and sufficient supply of air, that artificial expedients are generally resorted to, to secure that object. One of these consists in erecting large air pumps, such as those we have described above, at the summit of one of the shafts, by means of which the air is drawn from it, and consequently an upward current established in it. A simple, efficient, and cheap form of pumps, used for this purpose at the mines of the Harz mountains in Germany, is represented in *fig.* 184.

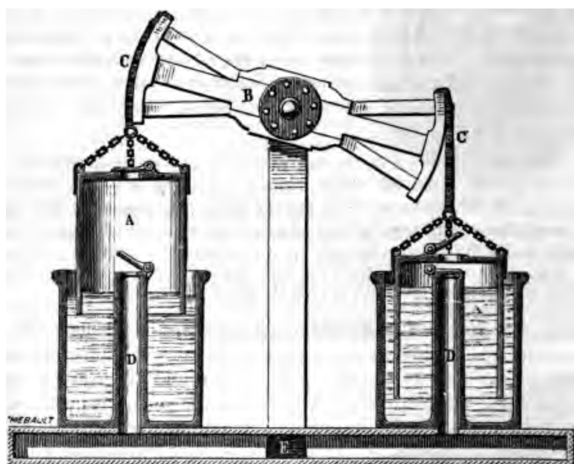


Fig. 184.

D D (*fig.* 184.) are two tubes which rise vertically above the surface of the water in two cisterns, a valve, opening upwards, being placed at the top of each. A A are two hollow cases, a little less than the cylinders, suspended from the beam B C, with their mouths downwards, also having valves at the top opening upwards. The pipes D D communicate with another pipe E, which leads to the shaft from which air is to be drawn. When either case A descends, the water entering it compresses the air, which closes the lower valve, and opens the upper, through which it escapes. When it is drawn up, the vacuum produced in A causes the air in D to open the lower valve, and issue into the case A. In this manner by the alternate motion of the beam, the air is at each stroke drawn from one tube through the lower valve, and discharged from the other case through the upper valve, and so the exhaustion is continued.

277. **Velocity of compressed gas escaping from an orifice.** — The great extension of gas illumination confers much prac-

tical interest on all physical questions respecting the movement of elastic fluids issuing from orifices or passing through pipes.

If a quantity of air or gas be inclosed in a vessel, in the side of which an opening is made, a current of air or gas will be established, either outwards or inwards, according as the pressure of the gas is greater or less than that of the surrounding atmosphere. If the pressure be greater, the gas in the orifice being pressed outwards with more force than inwards, it will rush out with a force proportionate to the difference of the pressures. If its pressure be less than that of the surrounding atmosphere, the air in the orifice being pressed inwards with more force than outwards, the atmosphere will rush in with a force proportionate to the difference of the pressures. If, in fine, the pressure of the included gas be equal to that of the atmosphere, no current will be established either inwards or outwards, the forces acting upon the air in the orifice being in equilibrium.

In the case of liquids it has been shown that the velocity of efflux from an opening in the side will be equal to the velocity which a body would acquire in falling from the level of the surface of the liquid to that of the orifice. In that case, however, the atmosphere presses as strongly on the surface of the liquid as on the orifice, and therefore does not affect the velocity of efflux. In the case, however, of the escape of compressed air or gas from an orifice in a closed vessel, the external atmosphere is excluded from any action on it except at the orifice, and therefore, in calculating the velocity of efflux, it is necessary to allow for the atmospheric pressure as a resisting force. If the vessel including the compressed air were surrounded by a vacuum, the velocity of efflux would be calculated upon exactly the same principles as have been applied in the case of liquids. The compressed air being regarded as a fluid of uniform density, it would be necessary to find the height of a column of that density, whose weight would be equal to the outward pressure at the orifice. This would be easily done if the specific gravity of the compressed air or gas be given. The velocity of efflux would then be equal to that which a body would acquire in falling through the height of a column of gas of that density, the weight of which would be equal to the pressure.

If, however, the efflux be resisted by the pressure of the surrounding atmosphere, the effective outward pressure will be only the difference between the pressure of the gas in the vessel and that of the atmosphere. To find the velocity of efflux in this case it is only necessary to imagine the vessel being opened at the top, and having sufficient depth to be filled with a liquid having the same uniform density as the gas contained in the vessel, and that its upper surface is at such a level that it would produce a pressure

at the orifice equal to the difference between the pressures of the condensed gas and of the atmosphere. The velocity of the efflux will then be that which a body would acquire in falling from the surface of such a liquid to the level of the orifice.

278. **Contracted gas vein.** — In issuing from an orifice, air or gas is subject to effects similar to those which produce the contracted vein in the efflux of liquids, and, as in that case, the velocity of efflux, calculated on the principle explained above, will be its velocity, not at the edges of the orifice, but at the most contracted part of the vein. In calculating the actual quantity of gas discharged through the orifice, the same conditions must therefore be observed as in the case of liquids, the product of the velocity of efflux, by the magnitude of the orifice, being reduced in the proportion of the magnitude of the orifice to that of the contracted vein. It is found by experience that when the orifice is a simple opening made in the thin side of a vessel, the actual discharge amounts to only 65 per cent. of the theoretical discharge; but if the gas be allowed to escape through a cylindrical pipe, or, still better, through a conical pipe slightly converging outwards, the discharge will be increased to 93 per cent. of the theoretical efflux.

279. **Movement of gas in pipes.** — When gas flows through pipes, it suffers from their sides a degree of friction which produces a considerable resistance to its motion. In the case of liquids, this resistance is found to increase in a higher proportion than the increase of the velocity, but in a less proportion than that of the square of the velocity. In the case of gas, however, for all velocities from 300 to 350 feet per second, the resistance may be taken as proportional to the square of the velocity.

A much greater degree of resistance to the flow of gas is produced by elbows on the pipes, and by contractions of their diameters, than by mere friction with the sides. Every change of direction of the pipes, therefore, should be made by curves as far as is practicable.

The draught of stoves is sensibly impeded by all elbows which are formed upon them.

Valves or dampers are introduced into stove pipes, and cocks into gas pipes, which, by throttling, in a greater or less degree, the current, moderate the draught in the one case, and regulate the flame in the other.

280. **Blowing engines.** — In the blast furnaces used in metallurgy, it is necessary to impel through the fuel great volumes of air with prodigious force. This is accomplished by blowing machines, which are in principle identical with the condenser already described, and which differ in nothing from the large

exhausting cylinder, represented in *fig.* 180., except in the position of the valves. If the valves to the left of that cylinder be supposed to open into pipes leading to the furnace, while the valves to the right open into the atmosphere, it will become a blowing cylinder; and at each stroke of the piston a volume of air, equal to its capacity, will be driven through the fuel.

As in the case of the forge-bellows, it is necessary here that the air should pass through the furnace in a continuous and nearly regular current, and not by puffs, as it would if it came directly from a blowing cylinder. The action of such a cylinder is equalised by interposing between it and the furnace another large cylinder, as represented in *fig.* 185., in which there is a loaded piston. Each time that a puff of air comes, this piston is raised, and, by yielding, moderates the current in the furnace. At each interval of intermission, the weighted piston, pressing on the air under it, sustains the current.

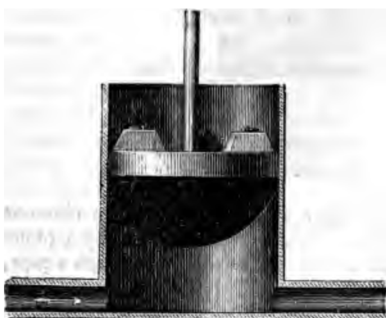


Fig 185

It will be evident that such an intermediate piston has the same equalising effect upon the air as a fly wheel has upon a crank.

The same apparatus may obviously be used for the ventilation of mines. In that case a current would be driven down one shaft, and, by the compression of air in the workings, a corresponding current would be driven up another.

281. **Winnowing machine.** — This machine consists of a hollow cylinder, having a small opening round its axis (*fig.* 186.), within which four or more flat vanes are kept in revolution. The air which enters at the opening, being thus put in revolution, is driven by the centrifugal force towards the surface of the cylinder, and thence up the sloping bottom, blowing before it the grain which descends from the hopper above. The chaff and lighter impurities are thus blown away, and the grain falls into a receptacle provided for it.

282. **Centrifugal blowing machines.** — Blowing machines for furnaces as well as for the ventilation of mines are constructed upon the same principle; the vanes, however, being curved so as to present their convex surfaces in the direction of their motion.

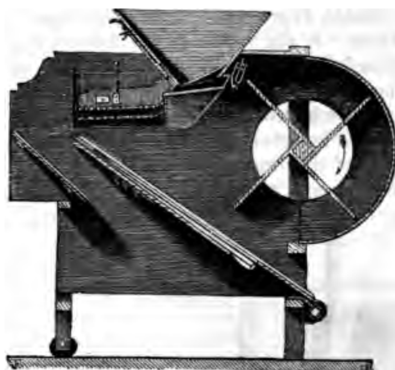


Fig. 186.

A vertical section of one of these cylinders, made by a plane at right angles to its axis, is shown in *fig.* 187., and one by a plane through its axis in *fig.* 188. The air is driven through a pipe

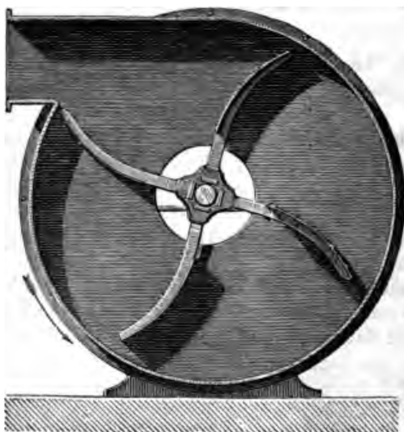


Fig. 187.

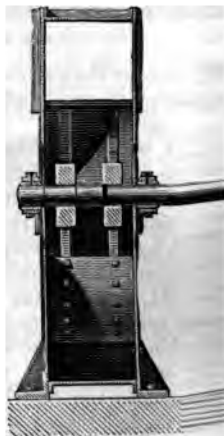


Fig. 188.

whose direction is tangential to the cylinder, and which leads the ventilating shaft. After what has been stated, the operation of this machine is so obvious, that any further explanation of it is needless.

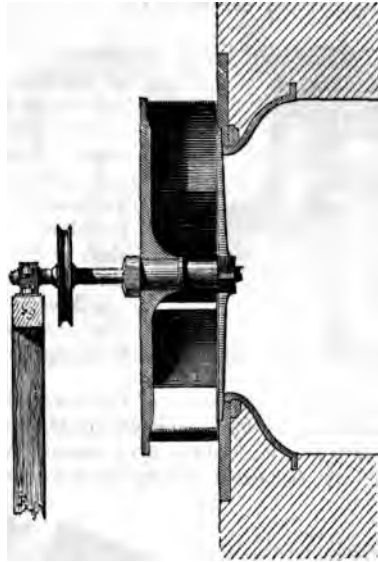


Fig. 189.

When such a cylinder is used for the ventilation of a mine, it is attached to the mouth of the shaft, as shown in *fig.* 189., the part covering the mouth being then open, so that there is free communication between the revolving vanes. The form and disposition given to the vanes, as shown in *fig.* 190., is due to M. Combes. The vanes are curved, the convexities being turned in the direction of the motion, the air escaping from the sides of the wheel which are completely open. The purpose of this arrangement is to give the air but a small velocity at the moment it leaves the wheel.

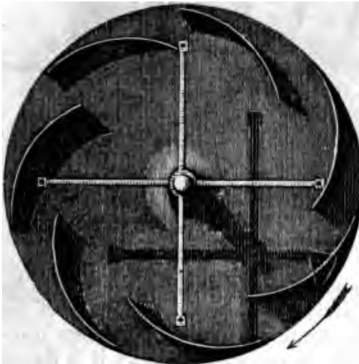


Fig. 190

283. **The pneumatic screw.** — The screw of Archimedes, already described in its application to the elevation of water and to the propulsion of ships, is also used for the ventilation of mines. It is erected over the shaft to be ventilated, as shown in *fig.* 191., and it drives air down the shaft or draws it up, according as it is turned in one direction or the other. The principle of its action being the same as in the other cases of its application, further explanation is needless.

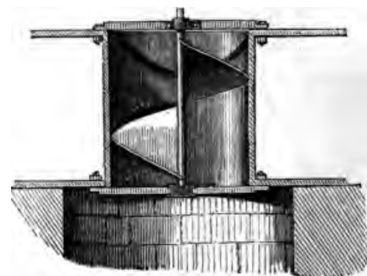


Fig. 191.

284. **Cagniardelle.** — The screw of Archimedes has been used as a blowing machine, in a form contrived by M. Cagniard de Latour, from whom it has received the above name. The instrument, as shown in *fig.* 192., is immersed obliquely in a cylinder; and the air, which enters its upper compartments c, being shut in there by the water, is screwed successively down, by the revolution of the machine, through the compartments c′ c″ c‴, being more compressed as it advances. In the lowest compartment it is forced by the compression into the tube D, which leads to the furnace, or to the shaft to be ventilated.

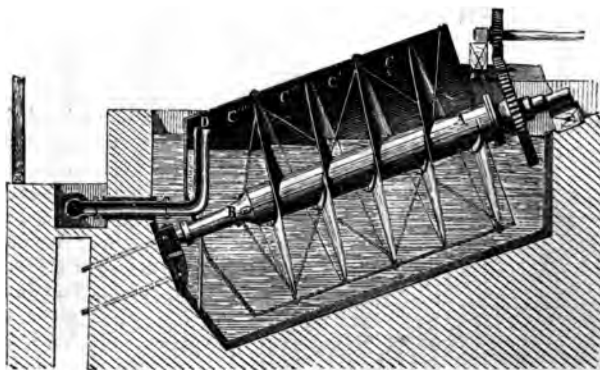


Fig. 192.

285. **Trompe.** — A blowing machine, thus called by French engineers, is represented in *fig.* 193. Water is let down from a

n through a vertical tube, into which air is at the same time :ted by lateral openings A A. The descending column, con-g of a mixture of air and water, falls upon a small horizontal :water C, in a closed cistern B; the air, being thus separated

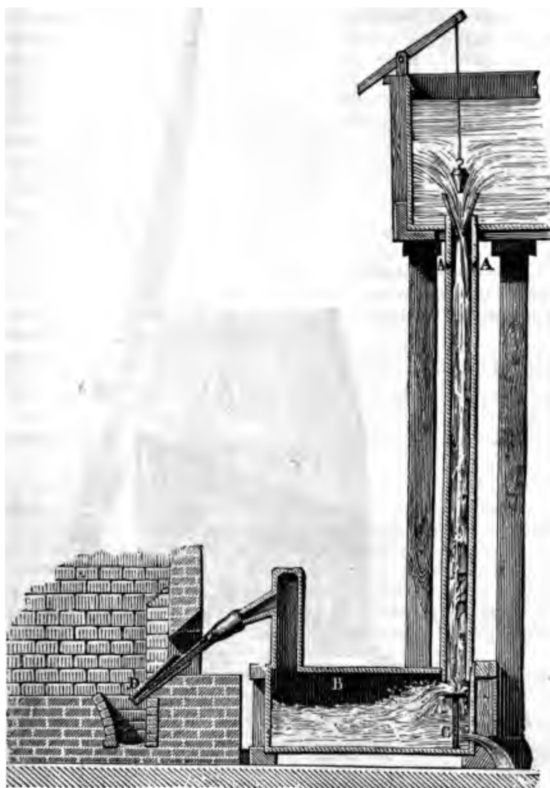


Fig. 193.

the water, is compressed in the upper part of the cistern, forced through a pipe or nozzle D, into the furnace, while the r is discharged from the cistern by a pipe near its bottom at C.

6. **Windmills.** — Since the infancy of the arts, the force of rind has been used as a moving power. It is still extensively for driving corn mills, and also, more or less, for the purposes ainage.

The vertical section of a corn mill, in its usual form, made by a plane passing through the axis of the sails, is represented in *fig.* 194.

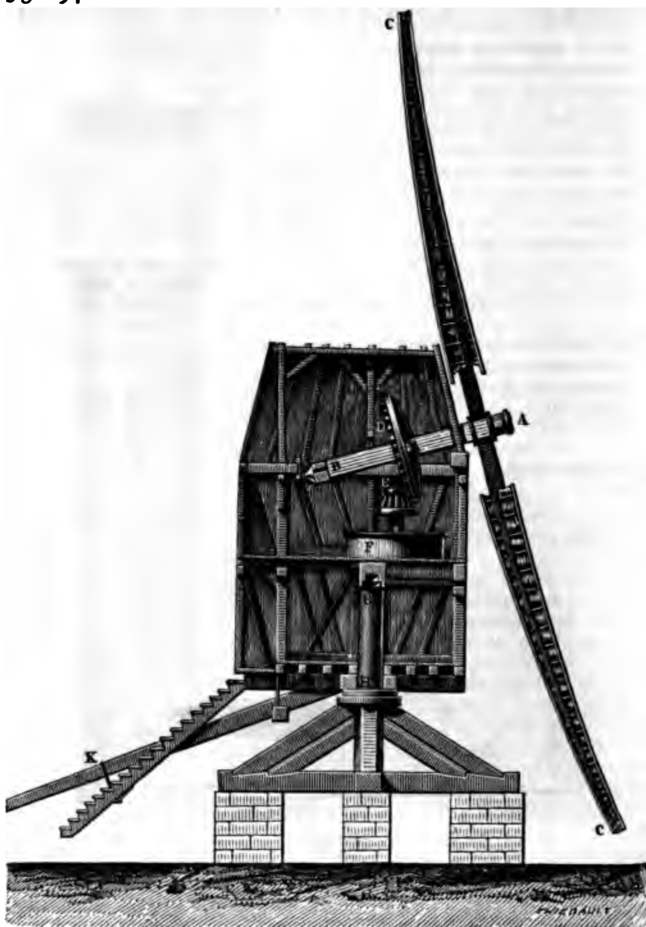


Fig. 194.

The axis A B, upon which the sails revolve, is inclined at an angle of 10 or 15 degrees to the horizon, the wind being found generally to blow downwards at about that angle. The entire structure is supported on a vertical

xis H G, upon which it can be turned by a long lever K, so as to present the ails to the wind whatever be its direction. The ladder for mounting into he mill is raised and moved by the same lever. A crown wheel D, which evolves with the shaft A B imparts motion to the vertical basket E, which is xed upon the shaft which turns the millstones F. The sails consist of four rms A C, placed at right angles, each of which is formed like a double ladder le centre pillar of the ladder being the arm, a ladder being thus ranged on ich side of it. Upon the rungs of these ladders canvass forming the sails is retched. It is evident that if the surface of this canvass were presented erpendicularly to the direction of the axis A B and that of the wind, no re-olution would be produced, the whole force of the wind having no other fect than to strain the arms of the mill; but by inclining the canvass at a roper angle to the direction of the wind, the force of the latter, as in the case ' the sails of vessels, is resolved into components, one of which will be rected at right angles to the arm of the mill.

The obliquity of the sail which produces the best effect varies with its dis-nce from the axis A B; and in order, therefore, to render the mill most ficient this obliquity must be varied, being greatest near the axis, and less wards the extremities. The ladder-formed frames on which the sails are read are therefore, in the original construction of the mill, so shaped as to ve the sails at each point the proper obliquity.

No one who considers the geometrical principles which determine the rm of the sails of a windmill, and who contemplates the arms of that ma-ine, can fail to be struck with their resemblance to the form of the feathers the wings of birds. The same geometrical principles which guide the eble efforts of the human machines are thus manifested in infinitely greater erfection in the works of the Author of Nature.

According to the varying force of the wind it is necessary, as in navigation, spread a greater or less quantity of canvass, and it is therefore requisite om time to time to have access to the sails, so as to increase or diminish eir extent. This is usually accomplished by arresting the progress of the ill by means of a break applied to the circumference of the wheel fixed upon le axis A B, and bringing the sails to rest when one of the arms is at its west point. A man then ascends upon the rungs of the arm as he would pon a ladder, and adjusts the sails in the desired manner; the same process eing repeated for each of the arms.

The inconvenience, difficulty, and delay of this operation, and a certain anger which attends it, has led a French millwright, M. Berton, to contrive form of sails, represented in *fig.* 195., which can be adjusted at pleasure ithout mounting the arm or even stopping the mill. The arms, instead of eing overspread with canvass, consist of a series of long laths, jointed and ounted like those of a Venetian blind. These are traversed by rods E E, irected at right angles to the arms, and the laths are moved by four acks, which are driven by a common pinion fixed upon the centre of he shaft, which receives its motion from the interior of the mill. The aths can be placed at any degree of obliquity to the direction of the wind, nd when the mill is stopped, they can be folded together, as shown in *g.* 196.

287. A siphon is an apparatus by which a liquid can be de-anted from one vessel to another without inverting or otherwise listurbing the position of the vessel from which the liquid is

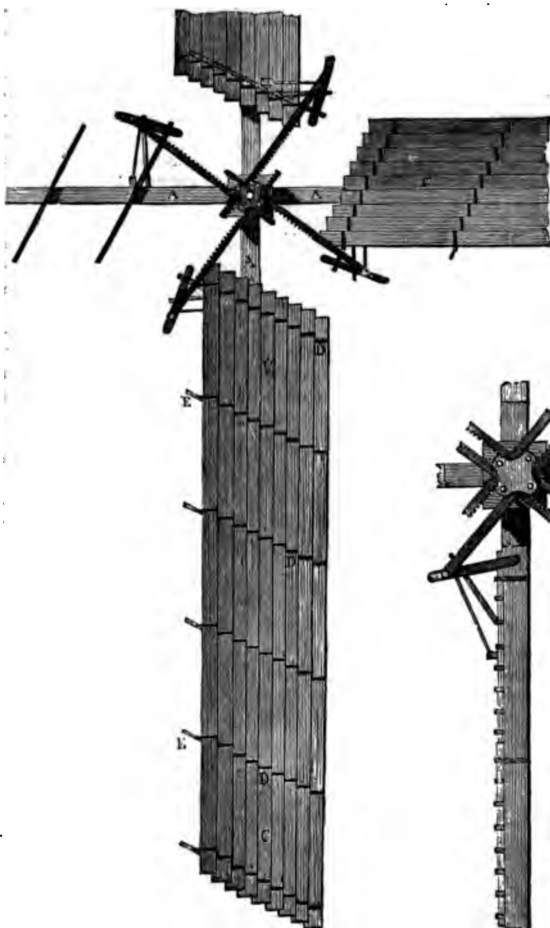


Fig. 195. Fig. 196.

removed. Let D, *fig.* 197., be a vessel containing a liquid, and let B be the height over which it is necessary to conduct the liquid, so as to transfer it to the vessel F G. Let A B C be a bent tube open at both ends, and let the leg B A be immersed in the liquid which it is

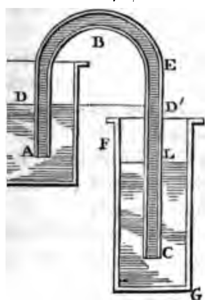


Fig. 197.

required to transfer, and let the leg B C be directed into the vessel into which the liquid is to be removed. Let the air which fills the tube A B C be drawn from it by the mouth placed at C, or by an exhausting syringe. The liquid in the vessel D will then be forced up in the pipe A B by the pressure of the atmosphere, and will fill the under tube to the mouth C. It will then flow through the siphon, and continue to be discharged at C so long as the level of the liquid in
sel D is above its level in the vessel F G.

evident that the bend of the siphon B cannot be at a greater ıbove the level of the liquid in D than corresponds with the ɔf a column of the liquid which the atmospheric pressure port. Thus, if the liquid to be decanted were mercury, ght of B above D should be less than 30 inches; and if it ater, it must be less than 34 feet.

ɔrinciple of the siphon is easily explained. Supposing the ube to be filled with liquid, we have the column extending iphon from the leg D to the highest point B, pressed up- ɔy the atmosphere acting upon the surface D, and trans- to it by the liquid in the vessel and in the tube. Against re is the weight of the column of liquid in the siphon, ex- from the leg D to the point B. The pressure, therefore, t the point B towards E is that of the atmosphere, diminished weight of a column of the liquid, whose height is that of the above the surface D.

we have at the point B another pressure opposed to this. nosphere pressing on the surface of the liquid at L is in like transmitted to the point B by means of the liquid in the G, and in the tube; but it is diminished by the weight of n of the liquid, whose height is that of the point B above face L. If the height of B, therefore, above the surface liquid in the two vessels were the same, the liquid at B be pressed equally in opposite directions by the common f the atmosphere, diminished by the weight of two equal s of the liquid. But so long as the column B L is greater e column B D, the effect of the atmospheric pressure acting towards D will be more diminished than its effect acting towards E, and consequently the liquid will flow in the lirection. In a word, the liquid will flow through the

siphon towards that vessel in which its level is lowest, and will continue so to flow until the levels be equalised.

The process of exhausting the siphon by suction or otherwise is often difficult, and always inconvenient. It may be avoided by inverting the siphon, and filling up the end of its longer leg, that of the shorter leg being temporarily stopped.

The siphon being once filled, and its mouths plugged, it may be inverted and placed in the vessel in the required position, when, the plugs being removed, it will commence to act.

A siphon is sometimes constructed as represented in *fig.* 198., having a suction or exhausting pipe, D E, attached to it, by which the process is facilitated.

The Wurtemberg siphon is so formed that when once filled it always remains so, provided the waste by evaporation be supplied. This instrument is represented in *fig.* 199.

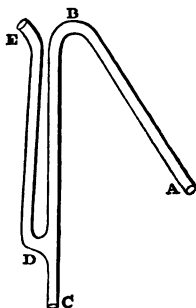


Fig. 198.

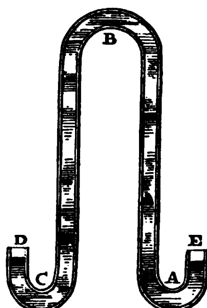


Fig. 199.

288. **Intermitting fountains.**—An apparatus to illustrate this class of pneumatic effects is shown in *fig.* 200. A glass vessel A, containing water, is terminated below by four openings B B, through which the water issuing is received in a cistern E. The vessel A is closed at the top; but a vertical tube C D, which is open at both ends, communicates with the air at the bottom of the cistern E, through which it passes. The pressure of the atmosphere, therefore, causes the water in A to flow through the orifices B B into the cistern E. In the bottom of this cistern there is a small hole O, through which water flows into a second cistern, in which the cistern E stands. But the discharge from O not being so rapid as that from B B, the level of the water in E continues to rise. When this level has risen to the mouth of the pipe D, it stops the further communication of air to A; and as the level falls in A, the air included in it, filling a larger space, exercises a diminished pressure on the surface of the water in A, the consequence of which

is, that the discharge from the pipes B B is continually decreased, until at length it becomes less than the discharge from O. When that happens, the cistern E, receiving less water from B B than it discharges at O, the level of the water in it falls, and this continues until the mouth of the pipe D is again uncovered, when, air being again admitted through the pipe to A, the pressure on the surface in A is restored, and the discharge from B B is the same as before.

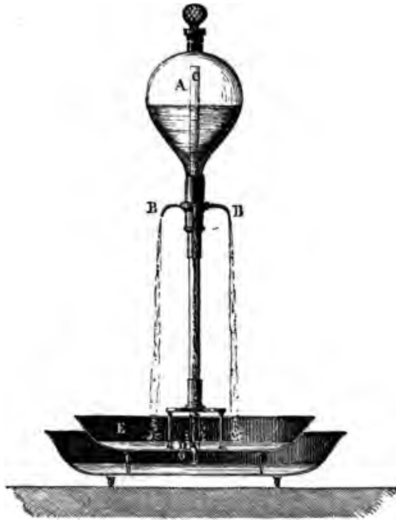


Fig. 200.

In this species of intermitting fountain, the flow from B B, is never absolutely suspended: it only becomes alternately more and less rapid.

Natural fountains exist, however, which actually cease to flow altogether in the intervals of their intermission. Such an effect may be imitated artificially, by the apparatus commonly called the cup of Tantalus, shown in *fig.* 201. Through the bottom of this cup the lower end of a siphon is inserted, which is bent round at C. If the cup be filled with water, the siphon will also be filled so soon as the level of the water in the cup rises above C, and the water will flow through the bottom of the cup, and will continue so to flow until the level A B of the water in the cup,

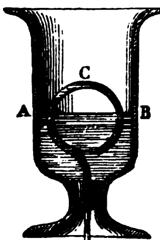


Fig. 201.

falls below the mouth of the siphon, when it will cease. If a supply of water to the cup be continued, the level A B will again rise, until it comes above C, when the flow from the bottom will recommence.

If we suppose a stream of water to fall into such a cup, at a slower rate than that with which it would be discharged by the siphon C, it is evident that the stream from the bottom of the cup would be intermitting. It would cease whenever the level A B would fall below the mouth of the siphon, which would always be the case after a certain interval, inasmuch as the discharge from the siphon is assumed to be more rapid than the supply.

When the discharge ceases, the supply will refill the cup, and the discharge will recommence when the level A B is raised above C.

Another form may be given to this apparatus, such as is represented in *fig.* 202. In this case, a straight pipe, passing through the bottom of the cup, rises to a point near the top; this is covered by a larger tube C, closed at the top and open at the bottom. When water is poured into the cup, it fills the tube C, in which the water remains at the same level as in the cup, until the level A B rises above the mouth of the discharge pipe. When this happens, the discharge pipe will be filled, and the apparatus will act in the same manner as that represented in *fig.* 201.

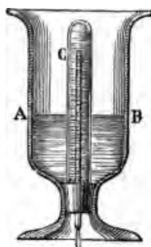


Fig. 202.

289. **Natural intermitting springs.**—These phenomena can be explained upon the same principle as that upon which the apparatus above described produce their effects.

Let us imagine a cavity to be formed in the interior of a hill, (*fig.* 203.) and that this cavity is filled with water, by a stream which leads to it from a much higher elevation. Let us further suppose that it communicates with a point of discharge in the side of the hill, by a siphon formed channel, more capacious than that by which the reservoir is filled. It is evident that when the level of the water in the reservoir, and the channel by

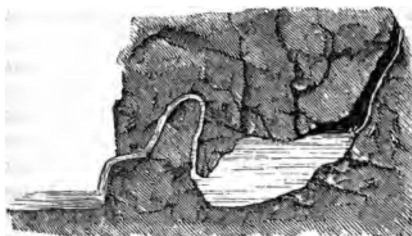


Fig. 203.

which it is supplied, rises above the bend of the siphon, the latter being filled, the discharge will commence, and if it is more rapid than the supply, the level of the water will subside below the mouth of the siphon, and the discharge will be suspended and the spring will cease to flow. The supply meanwhile being continued, the reservoir will be refilled, and so soon as the level of the water in it rises above the bend of the siphon, the discharge will recommence and the spring again flow.

290. **Hero's fountain.** — This is an expedient by which, by the interposition of compressed air, water can be made to rise above its original level. It takes its name from a celebrated philosopher who invented it, and who flourished at Alexandria about 120 B. C.

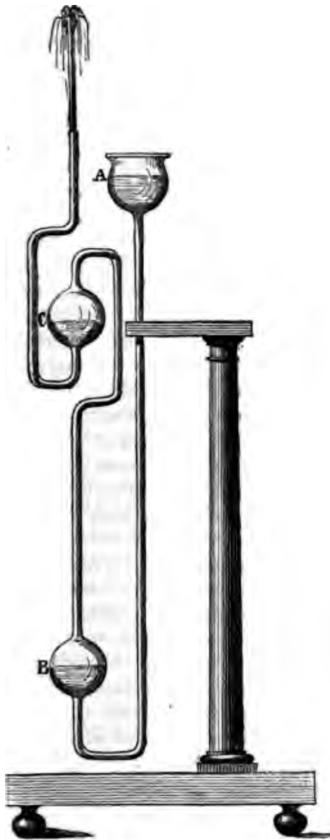


Fig. 204.

A reservoir A (*fig.* 204.) communicates by a bent tube with another, B, at a lower level, and this communicates again, by a bent tube, with C, at a level above it: a third bent tube proceeding from C, upwards, and extending above the level of A. Water is poured into A, and partially fills B; water has previously been poured into C, through the vertical pipe proceeding from it. By this arrangement air is included between the surfaces B and C, and is compressed by the weight of the column of water included between the levels of A and B. The pressure of this air being transmitted to C, will support a column of water as much above C as A is above B; and if the pipe proceeding upwards from C be terminated short of that height, a jet will be projected upwards from it, rising nearly to the same height.

291. **Pneumatic machines for raising water.**—We have already described the principal machines applied for this purpose, which depend upon the mechanical properties of water, and which are, properly speaking, hydraulic engines. We shall now notice those which depend for their operation, directly or indirectly, upon the mechanical properties of the atmosphere.

292. **The suction pump.** — By far the most common form of this class of engine, is the ordinary suction pump provided for domestic purposes.

A section of this useful apparatus is shown in *fig.* 205. It consists of a pipe or barrel, S O, which descends into the well, and the length of which must not exceed 34 feet. Attached to the top of this pipe, which is called the suction pipe, is a large syringe, acting precisely on the principle of a common exhausting syringe.

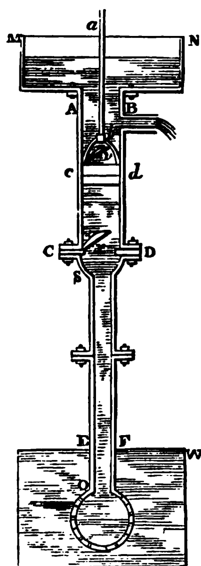


Fig. 205.

At the commencement of the operation, the pipe S E is filled with air to the level of the water in the well. The operation of the syringe draws the chief part of the air out of this pipe S E. When the water within the pipe is partially relieved from the atmospheric pressure, the weight of the atmosphere, acting upon the external surface of the water in the well, forces it up in the pipe S E; and according as the air is withdrawn by the syringe, the water continues to rise, until it passes through the valve x. This valve, opening upwards, prevents its return, since the weight of the column above it will keep it closed. When the barrel A C becomes filled with water, the syringe no longer acts as such, but works on the principle of the lifting pump, already explained. When the piston descends, the valve x is closed and the valve v opened, the water passing through the piston. When the piston is raised, the valve v is closed, and the column of water above the piston is projected upwards.

Meanwhile the pressure of the atmosphere on the water in the well causes more water to rise in the pump barrel following the piston.

The atmospheric pressure is capable of supporting a column of about 34 feet of water. It is evident, therefore, that such a pump as is here described can only be efficient when the piston is at a height of less than 34 feet above the surface of the water in the

well, since otherwise the atmospheric pressure would not keep the water in contact with the piston.

The suction pump, therefore, as compared with the lifting pump, saves 34 feet length of pump rod; but otherwise there is no comparative mechanical advantage.

It might appear at first view that the pressure of the atmosphere sustaining a column of water in the suction pipe, supplies aid to the power that works the pump, and spares an equivalent amount of that power.

This, however, is not the case, as will appear from a due consideration of all the forces which are in operation.

Of these forces there are some which are directed downwards from the top of the column raised by the piston towards the bottom of the well, and others which are directed upwards. Now it is evident that the mechanical power applied to draw the piston up will have to overcome all that excess by which the forces downwards exceed the forces upwards. Let us suppose a column of water resting on the piston, after having passed through the valve *v*. The upper surface of this column is pressed upon by the weight of the atmosphere; the piston has, therefore, this weight to sustain. It has also to sustain the weight of the water which is above it. The atmospheric pressure, acting also on the water in the well, is transmitted by the water to the bottom of the piston; but this effect is diminished by the weight of the column of water between the surface of the water in the well and the bottom of the piston, for the atmospheric pressure must, in the first place, sustain that column, and can only act upon the bottom of the piston in the upward direction with that amount of force by which it exceeds the weight of the column of water between the piston and the well. The effect, therefore, on the piston is the same as if it were pressed downwards by the weight of the column of water between the piston and the well, and at the same time pressed upwards by the atmospheric pressure. Thus the piston may, in fact, be regarded as being urged downwards by the following forces, — the atmospheric pressure, the weight of the water above the piston, and the weight of the water between the piston and the well; that is to say, in fact, by the atmospheric pressure, together with the weight of all the water which has been raised from the well. At the same time, it is pressed upwards by the atmospheric pressure transmitted from the surface of the water in the well. This upward pressure will destroy the effect of the same atmospheric pressure acting downwards on the surface of the water above the piston, and the effective downward force will be the weight of all the water which is contained in the pump.

By this reasoning, it appears that the pump must be worked

with as much force as is equal to the weight of all the water which is in it at any time, and, therefore, that the atmospheric pressure affords no aid to the working power.

Since the action of the pump in raising water is subject to intermission, the stream discharged from the spout will necessarily flow by fits and irregularly, if some means be not adopted to prevent this. At the top of the pump a cistern may be constructed, as shown in *fig*. 205., with a view to remove this inconvenience. If the pump be worked, in the first instance, so as to raise more water in a given time than is discharged at the spout, the column of water will necessarily accumulate in the barrel of the pump above the spout. The cistern M N will therefore be filled, and this will continue until the elevation of the surface of the water in the cistern above the spout will produce such a pressure that the velocity of discharge from the spout will be equal to the velocity with which the water is raised by the piston. The level of the water in the cistern will therefore cease to rise. This level, however, will be subject to a small variation as the piston rises; for, while the piston is descending, the water is flowing from the spout, and no water is raised by the piston, consequently the level of the water in the cistern falls. When the piston rises, water is raised, and the quantity in the cistern is increased faster than it flows from the spout, consequently the level of the water in the cistern rises, and thus this level alternately rises and falls with the piston. But if the magnitude of the cistern be much greater than the section of the pump barrel, then this variation in the surface will be proportionally small, for the quantity of water which fills a part of the barrel, equal to the play of the piston, will produce a very slight change in the surface of the water in the cistern. The flow, therefore, from the spout will be uniform, or nearly so.

The action of this sort of pump will be rendered still more easily intelligible by *fig*. 206., which represents the working model of a suction pump, usually provided for demonstrations in popular lectures. The pump handle H H′ raises and lowers the piston rod *a*. The pump barrel is formed of glass, so as to show the piston within it, having a valve opening upwards. The other parts of the apparatus are marked with letters corresponding with those of *fig*. 205.

293. Another form of pump, called the forcing pump, is attended with many advantages, and is extensively used. This instrument is represented in *fig*. 207. The suction pipe C B is similar to that of the suction pump. The piston *c d* is a solid plug without a valve.

The forcing pipe G H has at its base *e f* a valve V′ which opens upwards. When the piston *c d* is raised, the valve V is opened,

and the water rises from the suction pipe into the pump barrel. When the piston *c d* is pressed downwards, the valve v is closed,



Fig. 206.

and the water is forced by the pressure of the piston through the valve v′ into the force pipe, and thus while the operation is continued, at each upward motion of the piston water is drawn from the suction pipe into the pump barrel, and at each downward motion it is forced from the pump barrel into the force pipe.

In order to produce a continued flow of water in the force pipe, an air-vessel is often attached to force pumps. Such an appendage is represented in *fig*. 208.

When the piston descends, the water is driven through the valve v′ into the vessel which is closed and contains air. The force pipe G H descends into this vessel, and terminates near the bottom. The water which is forced in rises in it to a certain level, *w w′*, the air above it being compressed. The return of the water through the valve v′ being stopped, it is subject to the elastic

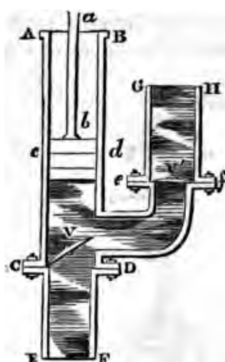


Fig. 207.

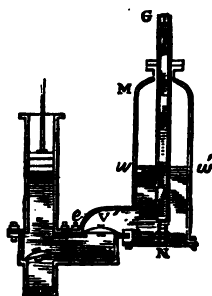


Fig. 208.

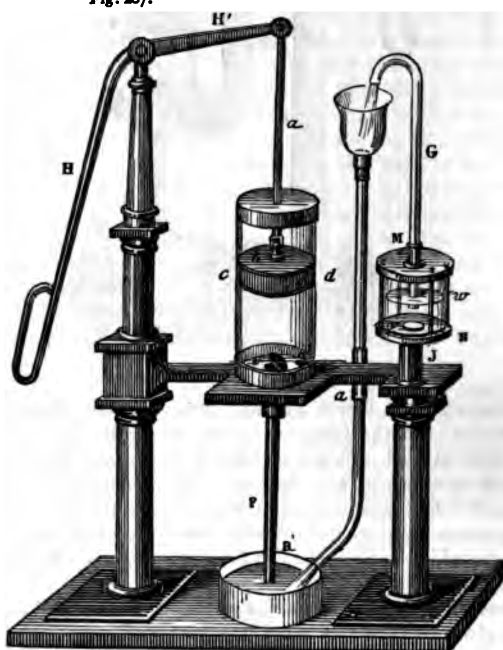


Fig. 209.

pressure of the air confined in the air-vessel M N. This pressure forces the water through the tube H G, from the top of



Fig. 210.

which it issues in a constant stream.

The forcing pump with its air-vessel, as constructed for demonstration at popular lectures, is shown in *fig.* 209., where all the parts are indicated by the same letters as in *figs.* 207. and 208. The water, which flows in a continual stream from the force pipe G, returns by the pipe *a* to the reservoir R, from which it is again raised by the pump.

The form in which this pump is generally constructed for domestic use is shown in *fig.* 210. The handle A B is a powerful iron lever, working on a centre at B, the extremity of the shorter arm C acting upon the end of the piston rod by means of the connecting rod C D. H is the suction pipe, F the suction valve, E the piston having a valve opening upwards, G a valve leading into the force pipe I, which is continued to any convenient height, the discharge pipe K, furnished with a stop-cock, supplies means of obtaining water at a lower level when required.

In the force pump, where the water acts upon the piston with a great pressure, it is portant that the piston should move in complete waterntact with the pump barrel. This is best accomplished ıccurately formed metallic plunger P (*fig.* 211.), work- ›ugh a collar of leather A B, which is exactly fitted to rith which it is made air-tight and water-tight, by being ed with oil or tallow. When this plunger is raised, the ; deserts is filled by the water which rises through the

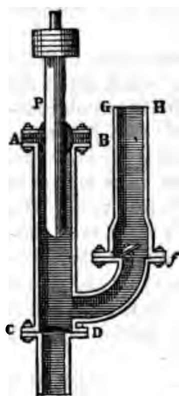


Fig. 211.

valve V, and when it descends, the water which filled the space into which it advances, is driven before it through the valve V into the force pipe.

294. If the forcing pump, represented in *fig.* 209., be attentively considered, it will be perceived that the principles on which the piston acts in its ascent and descent are perfectly distinct. In its ascent it is employed in drawing the water from the suction pipe into the pump barrel, and in its descent it is employed in forcing that water from the pump barrel into the force pipe. Now the piston being solid, and not furnished with any valve, there is no reason why its upper surface should not be employed in raising or propelling water as well as the lower. While the lower surface is employed in drawing water from the suction pipe, the upper surface might be employed in propelling water into the force pipe; and, on the other hand, in the descent of the piston, when the lower surface is employed in propelling water into the force pipe, the upper surface might be engaged in drawing water from the suction pipe. To accomplish this, it is only necessary that the top of the cylinder should be closed, and that the piston rod should play through an air-tight collar, the top of the cylinder communicating with the force pipe and the suction pipe, as well as the bottom.

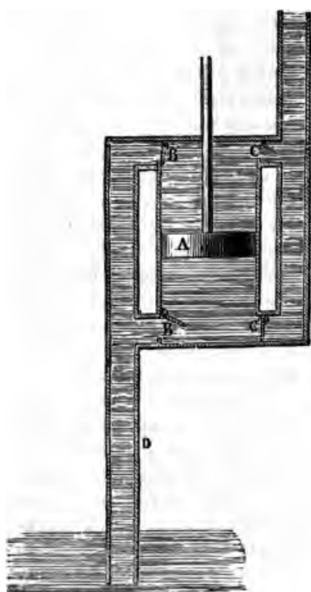


Fig. 212.

Such an arrangement is represented in *fig.* 212. When the piston A ascends, the suction valve B is opened, and water is drawn into the pump barrel below the piston; and when the piston descends, the suction valve B is closed, and the pressure of the piston on the water

below it opens the valve C′, and propels the water into the force pipe F. Also, while the piston is descending, water enters through the suction valve B′ into the barrel above the piston; and when the piston ascends, the water, being pressed upwards, keeps the valve B′ closed, and opens the valve C, and is thus propelled into the force pipe. By this arrangement the force pipe receives a continual supply of water from the pump barrel without any intermission; and in like manner the pump barrel receives an unremitting flow from the suction pipe D. This will be distinctly seen, if it is considered that one of the two valves B or B′ must always be open. If the piston go down, B′ is open and B closed; if it go up, B′ is closed and B open. A stream, therefore, continually flows through one valve or the other into the pump barrel. In like manner, whether the piston ascend or descend, one of the valves C or C′ must be open.

295. The fire-engine is a double forcing pump, each barrel of which acts upon the principle explained above.

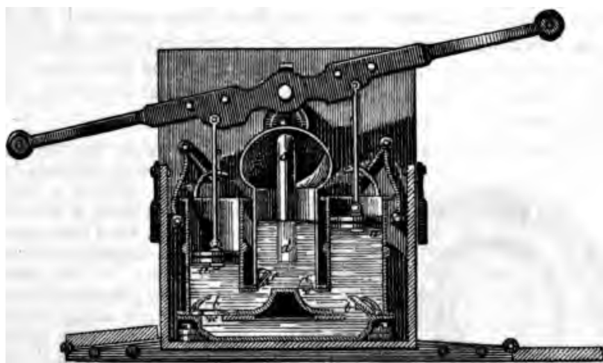


Fig. 213.

A section of such an engine, in its most usual form, is represented in *fig.* 213., and a plan in *fig.* 214.

The solid pistons *a a* are alternately forced down upon the water which has been drawn into the barrels upon the principles already explained, and the water is thus forced into the air vessel *e*. The reaction of the compressed air drives the water with a proportionate force through the force pipe *d* into a long, flexible, leathern hose, upon the end of which a large jet pipe is screwed. The firemen carry this jet pipe near to or into the building on fire, and with it throw up to great heights a constant stream of water, which, falling on the burning bodies, extinguishes the fire.

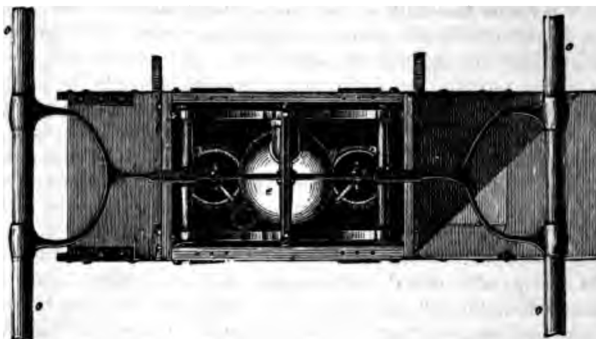


Fig. 214.

296. **Centrifugal pumps.** — Machines for raising water, depending upon the principle of centrifugal force, have lately attracted much attention, and some have been contrived which combine in a high degree simplicity of construction with efficiency.

The general principle of their operation will be understood by reference to *fig.* 215., which represents the vertical section of one of the most common forms.

The lower pipe is the suction, and the upper the force pipe; the course of the water being indicated by the arrows. Within a fixed cylinder is included a movable one A A (*fig.* 215.), rotating on a fixed axis concentric with the fixed cylinder. In this rotating cylinder are inserted four plates, C C C C, which extend from end to end, being nearly but not quite in contact with the ends of the fixed cylinder. These four plates are inserted in openings of corresponding magnitude, in the rotating cylinder A A. Within the fixed cylinder there is a bent surface, against which the edges of the plates C press as they pass the openings of the force and suction pipes, and by this they are driven into the revolving cylinder B B, being entirely within it, at the moment they severally pass the point between the force and suction pipes.

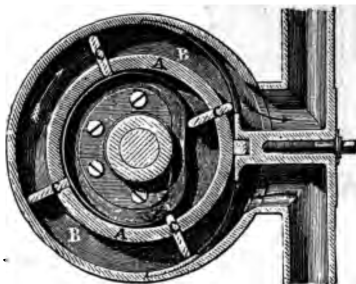


Fig. 215.

After passing this point, the internal edges of this plate come into contact with a curved surface, shown in the figure, by which they are again pressed out.

It will, therefore, be understood that these four plates C divide the space between the rotating and fixed cylinders into four compartments, and that any fluid which is between two of these plates is whirled round the intermediate

space B B, a continual tendency to fly outwards being imparted to it by the centrifugal force thus produced. In consequence of this such fluid, in passing the mouth of the force pipe, is driven into it.

At the commencement of the operation, and before any water is raised in the suction pipe, air enters from the latter into the first compartment of the cylinder, and, being carried round by the plate C, is discharged into the force pipe. In this way the machine acts as an air pump, exhausting the suction pipe in which the water consequently ascends, and, being drawn into the cylinder, is carried round by the plate C, and driven up the force pipe.

It will be evident, therefore, that this machine not only acts as a suction and force pump, but produces an unintermitting current.

Appold's centrifugal pump.—Mr. Appold produced at the Great Exhibition in the Crystal Palace a form of centrifugal pump, for which the Council Medal was adjudicated to him. In this pump the water is admitted through a circular opening surrounding the axis, with which the fan is connected. The blades of the fan are each three inches wide, and revolve within a circle 12 inches in diameter, the diameter of the central opening for the admission of the water being 6 inches. The fan is composed of 6 curved arms, having the form represented in section in *fig.* 216., the scale of the figure being 1 inch to a foot. The curves are so arranged that the extremities of the arms move tangentially. The blades of the fan are fixed on the driving shaft, which, passing through a stuffing box in the side of the casing, works between two circular cheeks, running close to them, but without actual contact. The outer revolving surfaces are thus shielded from the water, to which a free ingress is given, and a large space is left all round the circumference of the fan to facilitate the escape of the discharged water.

In order to show the advantage of curved arms over straight ones, whether placed obliquely, as in *fig.* 217., or straight, as in *fig.* 218., Mr. Appold provided means of interchanging these different systems, so that the effect of each could be shown with the same pump. It resulted from the experiments made by the jury, that, with a lift of 19½ feet and a velocity of 788 revolutions per minute, and a circumferencial velocity of 2476 feet per minute, the discharge amounted to 1236 gallons per minute, and the useful effect was 68 per cent. of the power. With nearly the same lift, a fan, having straight inclined arms, such as shown in *fig.* 217., with a rotatory velocity of 690 revolutions per minute, and a circumferencial velocity of 2168 feet per minute, the discharge was 736 gallons, and the useful effect amounted to only 43 per cent. of the power. With straight radial arms, as shown in *fig.* 218., and nearly the same velocity, the discharge was reduced to 474 gallons, and the useful effect to 24 per cent. of the power.

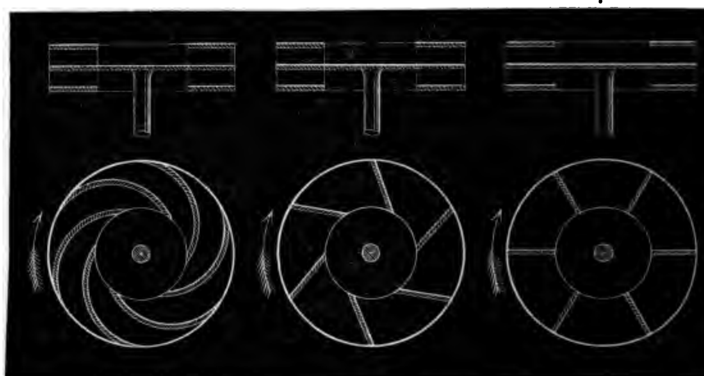


Fig. 216. Fig. 217. Fig. 218.

Mr. Appold claims, however, a useful effect of 72 per cent. with a circumferencial velocity of 1627 feet per minute, by observing precautions which could not be adopted in the experiments made at the Great Exhibition.

297. The purpose to which pumps are applied on the most vast scale is in the drainage of mines. In that case the power required far exceeds the limit to which animal power is practically available; and even steam power, by which such pumps are worked, requires to be applied on a scale far exceeding every other form in which it has been applied in the industrial arts.

In such cases the water is required to be elevated from the level of the workings, through a vertical shaft or series of shafts, to a height which often amounts to many hundred yards. It would be generally impracticable to raise it by a single force pump; for the pressure upon the plunger would be too great for the practical working of the machine. However accurately the pump might be constructed, water would force itself, more or less, between the plunger and the barrel, and would thereby produce a corresponding waste of power.

The object has, therefore, been attained by placing separate pumps at successive levels, having a common rod A A (*fig.* 219.), worked by a steam-engine erected at the mouth of the shaft. Two pumps of such a series are represented at B and B′. The pump B forces the water up the pipe C *c*, where it is discharged into the cistern D′, from which it is again forced by the pump B′ to the next level, and so on.

298. **Versailles waterworks.**—The machines by which the

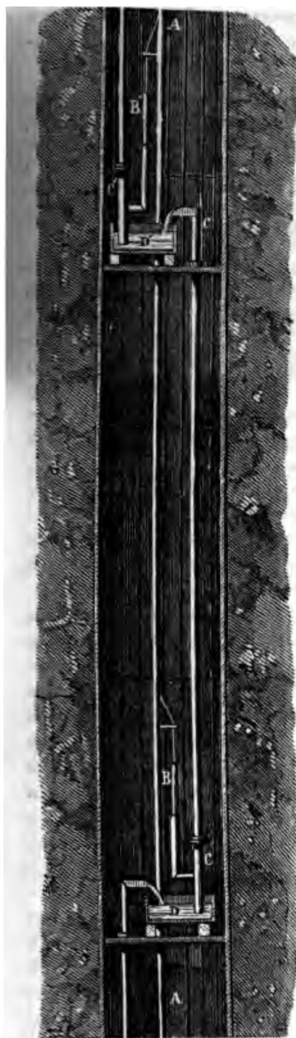


Fig. 219.

ornamental waterworks in the gardens of Versailles are supplied are, if not the most powerful, certainly the most celebrated, hydraulic works in Europe, especially when the date of their construction is considered. These machines were originally constructed, under Louis XIV., for the supply of the palace and waterworks at Marly, but were afterwards augmented in magnitude and power for Versailles. They were completed in 1682.

Marly is situate upon a summit 500 feet above the level of the Seine. A large reservoir and aqueduct were constructed at this level, which, being above that of Versailles, is sufficient to give play to the waterworks at the latter place.

The water was originally raised from the Seine to the aqueduct by the power obtained from fourteen overshot hydraulic wheels, each 40 feet in diameter, which worked three systems of pumps placed at different levels.

Great changes and improvements have since been made in these machines, and at present the water is forced through a large metal main by a system of force pumps, driven partly by two of the original fourteen wheels, and partly by a powerful steam-engine which was erected for that purpose in 1826.

There are sixteen force pumps, eight of which are worked by the two hydraulic wheels which still remain, and the other eight by the steam-engine. The column of water sustained in the force pipe produces, when at rest, a pressure of fifteen atmospheres, and since it has been proved that the force exerted by the plungers amounts to seventeen atmospheres, it follows that

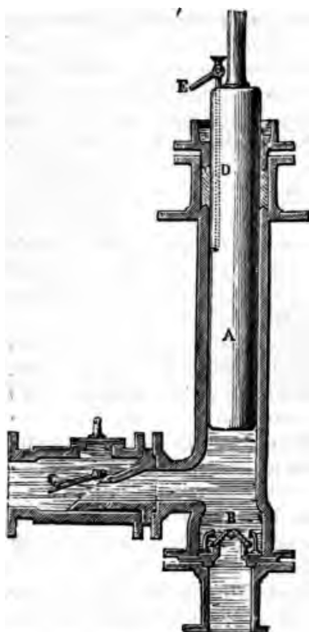


Fig. 220.

the resistances due to friction and other causes, amount in this machine to two atmospheres.

A section of one of the force pumps at present used is shown in *fig.* 220., where B is the suction valve, C the force valve, A the plunger, and D a small opening, by which the air, occasionally collecting in the pump barrel, can be discharged.

299. **Measure of the discharge of pumps by an inch of water.**—Hydraulic engineers have agreed to express the quantity of water discharged in a given time from a pump by a certain hydraulic unit, to which they have given the name of the inch of water.

To explain this, let us suppose a circular orifice made in the side of a reservoir, the highest point of which is the twelfth of an inch below the level of the surface, and let the reservoir be so supplied with water that the surface shall be kept at that constant level, notwithstanding the discharge from the orifice. In that case, the rate of discharge from the orifice is called the inch of water, and is the hydraulic unit by which the discharge from pumps is expressed. A pump, for example, which would discharge ten times as much water per minute, would be said to have a discharge of ten inches, and so on.

BOOK THE THIRD.

HEAT.



CHAPTER I.

PRELIMINARY PRINCIPLES AND DEFINITIONS.

300. HEAT, like all other physical agents, is manifested and measured by its effects.

301. One of the most familiar of these is the sense of more or less warmth which a body, when it receives or loses heat, produces upon our organs.

When the heat received or lost by a body is attended with this sense of increased or diminished warmth, it is called *sensible heat*.

302. But it will occur in certain cases that a body may receive a very large accession of heat without any increased sense of warmth being produced by it, and may, on the other hand, lose a considerable quantity of heat without exciting any diminished sense of warmth. The heat which a body would thus receive or lose without affecting the senses is called *latent heat*.

303. When a body receives or loses heat, it generally suffers a change in its dimensions, the increase of heat being usually attended with an increase, and the diminution of heat with a diminution of volume. This enlargement of volume due to the accession of heat is called *dilatation*, and the diminution of volume attending the loss of heat is called *contraction*. There are, however, certain exceptional cases in which heat, whether received or lost, is attended with no change of volume, and others in which changes take place the reverse of those just mentioned; that is to say, where an accession of heat is accompanied by a diminution, and a loss of heat with an increase of volume.

304. If heat be imparted in sufficient quantity to a solid body, it will pass into the liquid state. Thus, ice or lead, being solid, will become liquid by receiving a sufficient accession of heat. This change is called *fusion* or *liquefaction*. If heat be abstracted in sufficient quantity from a body in the liquid state, it will pass

into the solid state. Thus, water or molten lead losing heat in sufficient quantity will become solid. This change is called *congelation* or *solidification*; the former term being applied to substances which are usually liquid, and the latter to those that are usually solid.

305. If heat be imparted in sufficient quantity to a body in the liquid state, it will pass into the state of vapour. Thus, water being heated sufficiently will pass into the form of steam. This change is called *vaporisation*. If a body in the state of vapour lose heat in sufficient quantity, it will pass into the liquid state. Thus, if a certain quantity of heat be abstracted from steam, it will become water. This change is called *condensation*; because, in passing from the vaporous to the liquid state, the body always undergoes a very considerable diminution of volume, and therefore becomes condensed.

306. Heat, when imparted to bodies in a certain quantity, will in some cases render them luminous. Thus, if metal be heated to a certain degree, it will become *red hot*; a term signifying merely that it emits red light. This luminous state, which is consequent on the accession of heat, is called *incandescence*.

The more intense the heat is which is imparted to an incandescent body, the more *white* will be the light which it emits. When it first becomes luminous, it emits a dusky red light. The redness becomes brighter as the heat is augmented, until at length, when the heat becomes extremely intense, it emits a white light resembling solar light. A bar of iron submitted to the action of a furnace will exhibit a succession of phenomena illustrative of this.

307. Certain bodies, when surrounded by atmospheric air, being heated to a certain degree, will enter into chemical combination with the oxygen gas which forms one of the constituents of the atmosphere, This combination will be attended with a large development of heat, which is accompanied usually by incandescence and flame. This phenomenon is called *combustion*, and the bodies which are susceptible of this effect are called *combustibles*. The flame, which is one of the effects of combustion, is gas rendered incandescent by heat.

308. The degree of sensible heat by which a body is affected, is called its *temperature*, and the instruments by which the temperature of bodies is indicated and measured are called *thermometers* and *pyrometers*; the latter term being applied to those which are adapted to the measurement of the higher order of temperatures.

Changes of temperature are indicated and measured by the change of volume which they produce upon bodies very susceptible of dilatation. Such bodies are called *thermoscopic bodies*. The principal of these are, for thermometers, mercury, alcohol, and

air; and, for pyrometers, the metals, and especially those which are most difficult of fusion.

309. When heat is communicated to any part of a body, the temperature of that part is momentarily raised above the general temperature of the body. This excessive heat, however, is gradually transmitted from particle to particle throughout the entire volume, until it becomes uniformly diffused, and the temperature of the body becomes equalised. This quality, in virtue of which heat is transmitted from particle to particle throughout the volume of a body, is called *conductibility*.

Bodies have the quality of conductibility in different degrees; those being called good conductors in which any inequality of temperature is quickly equalised, the excess of heat being transmitted with great promptitude and facility from particle to particle. Those in which it passes more slowly and imperfectly through the dimensions of a body, and in which, therefore, the equilibrium of temperature is more slowly established, are called imperfect conductors. Bodies in which the excess of heat fails to be transmitted from particle to particle before it has been dissipated in other ways, are called non-conductors.

The metals in general are good conductors, but different metals have different degrees of conductibility. The earths and woods are bad conductors, and soft, porous, and spongy substances still worse.

310. Heat is propagated from bodies which contain it by radiation in the same manner, and according to nearly the same rules, as those which govern the radiation of light. Thus, it proceeds in straight lines from the points whence it emanates, diverging in every direction, these lines being called *thermal rays*.

311. Certain bodies are pervious to the rays of heat, just as glass and other transparent media are pervious to the rays of light. They are called *diathermanous* bodies. Thus atmospheric air and gaseous bodies in general are diathermanous.

The rays of heat are reflected and refracted according to the same laws as those of light. They are collected into foci by spherical mirrors and lenses, they are polarised both by reflection and refraction, and are subject to all the phenomena of double refraction by certain crystals in a manner analogous to that which takes place in relation to the rays of light.

Bodies are diathermanous in different degrees. Imperfectly diathermanous bodies transmit some of the rays of heat which impinge on them, and absorb others; the portions which they absorb raising their temperature, but those which they transmit not affecting their temperature.

312. The surfaces of bodies reflect heat in different degrees;

those rays which they do not reflect they absorb. The degrees of transmission, absorption, and reflection vary with the nature of the body and the state of its surface with respect to smoothness, roughness, or colour.

313. Rays of heat, like those of light, are differently refrangible.

314. The term heat is used in different senses: first, to express the sensation produced when we touch a heated body or are surrounded by a hot medium; secondly, to express the quality of the body by which this sensation is produced; and thirdly, to express the physical agent, whatever it be, to which the quality of the body is due. Notwithstanding these different senses of the same term, no confusion or obscurity arises in its use, the particular sense in which it is applied being generally evident by the context; nevertheless it is to be desired that writers on physics could agree upon a nomenclature more definite. The term *caloric* has been proposed, and to some extent adopted, to express the physical agent to which the effects of heat are due.

315. Two hypotheses have been proposed to explain the phenomena of heat. The first regards heat as an extremely subtle fluid, pervading all space, entering into combination in various proportions and quantities with bodies, and producing by this combination the effects of expansion, fusion, vaporisation, and all the other phenomena above mentioned. The second hypothesis regards it as the effect of the vibration or undulation, produced either in the constituent molecules of bodies themselves, or in a subtle impenetrable fluid which pervades them.

In the present Book the effects of heat will be explained independently of hypothesis; and, when they have been fully developed, the different theories proposed for their explanation will be stated.

CHAP. II.

THERMOMETRY.

316. **Measures of temperature.** — Of all the various effects of heat, that which is best adapted to indicate and measure temperature is dilatation and contraction. The same body always has the same volume at the same temperature, and always suffers the same change of volume with the same change of temperature.

Since the volume and change of volume admit of the most exact

measurement and of the most precise numerical expression, they become the means of submitting the degrees of warmth and cold, or, which is the same, the degrees of temperature, to arithmetical measure and expression.

317. Although all bodies whatever are susceptible of dilatation and contraction by change of temperature, they are not equally convenient for thermoscopic agents. For reasons which will become apparent hereafter, the most available thermoscopic substance for general purposes is mercury.

318. **Mercurial thermometer.** — The mercurial thermometer consists of a capillary tube of glass, at one end of which a thin spherical or cylindrical bulb is blown, the bulb and a part of the tube being filled with mercury.

When such an instrument is exposed to an increase of temperature, the glass and mercury will both expand. If they expanded in the same proportion, the capacity of the bulb and tube would be enlarged in the same proportion as the mercury contained in them, and, consequently, the column of mercury in the tube would neither rise nor fall, since the enlargement of its volume would be exactly equal to the enlargement of the capacity of the bulb and tube. If, however, the expansion of the bulb and tube be different from that of the mercury, the column in the tube will, after expansion, stand higher or lower than before, according as the expansion of the mercury is greater or less than the expansion of the bulb and tube.

It is found that the dilatability of mercury is greater than the dilatability of glass in the proportion of nearly 20 to 1, and, consequently, the capacity of the bulb and tube will be less enlarged than the volume of the mercury contained in them in the proportion of nearly 1 to 20; consequently, for the reason above stated, every elevation of temperature by which the mercury and tube would be affected will cause the column of mercury to rise in the tube, and every diminution of temperature will cause it to fall.

The space through which the mercury will rise in the tube by a given increase of temperature will be greater or less according to the proportion which the tube bears to the capacity of the bulb. The smaller the proportion the tube bears to the capacity of the bulb, the greater will be the elevation of the column produced by a given increase of temperature; for a given increase of temperature will produce a definite increase of volume in the mercury, and this increase of volume will fill a greater space in the tube in proportion to the smallness of the tube compared with the capacity of the bulb.

Such an instrument, without other appendages or preparation, would merely indicate such changes of temperature in a given place as would be sufficient to produce visible changes in the elevation of the column of mercury sustained in the tube. To render

it useful for the purposes of science and art, and in domestic economy, various precautions are necessary, which have for their object to render the indications of different thermometers comparable with each other, and to supply exact numerical indications of measurement of the changes of temperature.

319. **Process of construction.** — For this purpose it is necessary, in the first instance, that the mercury with which the tube is filled shall be perfectly pure and homogeneous. This object is attained by the same means as have been already explained in the case of the barometer (217.).

320. In the selection of the tube it is necessary that it be capillary, that is to say, a tube having an extremely small bore, and that the bore should be of uniform magnitude throughout its entire length. The smallness of the bore is essential to the sensibility of the instrument, as already explained; and its uniformity is necessary in order that the same change of volume of the mercury should correspond to the same length of the column in every part of the tube.

The uniformity of the bore of the tube may be tested by letting into it a small drop of mercury, sufficient to fill about a third of an inch of the tube. Let this be made to fall gradually through the entire length of the tube, stopping its motion at intervals, and let the space it occupies at different parts of the tube be measured. If this space be everywhere the same, the bore is uniform; if not, the tube must be rejected.

321. The bulb, whether spherical or cylindrical, can be formed upon the end of the tube by the ordinary process of glassblowing. The sensibility of the thermometer requires that the capacity of the bulb should bear a large proportion to the calibre of the tube. If, however, the capacity of the bulb be considerable, the quantity of mercury it contains may be so great that it will not be affected by the temperature of the surrounding medium with sufficient promptitude.

A cylindrical bulb of the same capacity will be more readily affected by the temperature of the surrounding medium than a spherical bulb, since it will expose a greater surface.

The glass of which the bulb is formed should be as thin as is compatible with the necessary strength, in order that the heat may pass more freely from the external medium to the mercury.

322. The tube to be filled is represented in *fig.* 221. C is a reservoir formed at the top for the purpose of filling it, which is to be afterwards detached. Let the tube be first dried by holding it over the flame of a spirit-lamp, so as to evaporate and expel all moisture which may be attached to the inner surface of the glass. To fill it, let a quantity of purified mercury be poured into the reservoir C. This will not fall through the bore, being prevented by the air included in the reservoir AB and in the tube. To

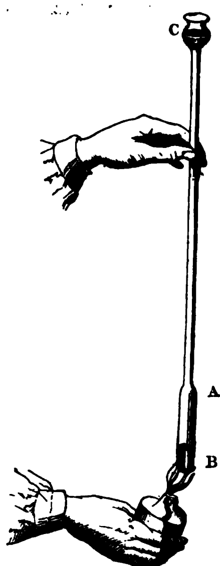


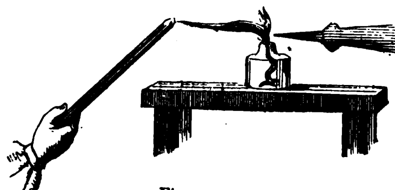
Fig. 221.

expel this, and cause the mercury to take its place, let the tube be placed in an inclined position over a charcoal fire or the flame of a spirit-lamp, so that the air shall be heated. When heated the air will expand, force itself in bubbles through the mercury in C, and escape into the atmosphere. This will continue until all the air in the bulb and tube has been expelled. The pressure of the atmosphere acting on the mercury in C will then force it through the tube into the bulb A B, which, as well as the entire length of the tube, it will ultimately fill. If a sufficient quantity of mercury be supplied to the reservoir C, the bulb A B, the tube, and a part of the reservoir C, will be filled with mercury after all the air has been expelled.

When this has been accomplished, let the tube be removed from the source of heat, and allowed gradually to cool. A file applied at C, where the top of the tube is joined to the superior reservoir, detaches that reservoir from the tube, which remains with the bulb A B completely filled with mercury.

In this state the instrument would give no indication of change of temperature, no space being left for exhibiting the play of the mercury by dilatation and contraction.

To obtain space for this, let the bulb A B be exposed to a temperature higher than any which the instrument is intended to indicate. The mercury dilating will then overflow, and will continue to overflow until it acquires the extreme temperature to which it is exposed.


Fig. 222.

A jet of flame being now directed by a blow-pipe (*fig.* 222.), on the end C, it will be hermetically sealed; after which, being

allowed to cool, the mercurial column will subside, the space in the tube above it being a vacuum, since the air is expelled. The column will continue to subside until the mercury assumes that state which corresponds to the temperature of the air surrounding the instrument.

323. **Thermometric scale.** — The variation of the height of the mercurial column in such a tube will in all cases correspond with the changes of temperature incidental to the surrounding medium; but, in order that it may supply a numerical expression and measure of such changes, a scale must be attached to the tube, by which the variations of the column may be indicated, and the divisions of the units of such scale must correspond to some known change of temperature. It is evident that such a scale, like all other standards for the arithmetical measure of physical effects, must be to some extent arbitrary. We accordingly find different scales and different thermometric units prevailing in different countries, and even in the same country at different times.

324. Whatever thermometric unit be adopted, it is necessary that two standard temperatures be selected, to which the mercury can be reduced at the times and places where thermometers may be required to be constructed or verified. The instrument being exposed to these two temperatures, the points at which the mercurial column stands are marked upon the scale. The space upon the scale between these points is thus divided into a certain number of equal parts, which are called degrees, these degrees being the thermometric units. The same divisions are then continued upon the scale above the higher and below the lower standard point, and such divisions may be continued indefinitely. The scale is then complete.

In this process, the number of equal parts into which the space between the standard points is divided, is altogether arbitrary.

325. It now remains to number the scale; and, for this purpose, a zero point must be selected. If there existed a minor limit to temperature,— a temperature below which no body could possibly fall,—then such a temperature would supply a natural thermometric zero, and the scale might be numbered upwards from it. In that case, although the thermometric unit would still remain arbitrary, the zero of the scale would not be so. But no such natural thermometric zero exists.

There is no natural limit either to the increase or diminution of temperature. The zero, therefore, of the thermometric scale, like the thermometric scale itself, must be arbitrary.

Thermal phenomena present great varieties of standard temperatures, by which thermometric scales may be established, and which may serve equally as terms of temperature for the purpose

distinguishing the indications of thermometers constructed different times and places. Thus, the temperatures at which solid bodies fuse, and those at which all liquids congeal, are ed. For different bodies these are different, but always the ne for the same body. In like manner, the temperatures at ich all liquids boil under a given pressure are invariable for the ne liquids, though different for different liquids. The tempera- e of the blood in the human species presents another example a fixed temperature.

326. Now any two of these various temperatures naturally fixed ght be taken as the thermometric standards, the choice being ogether arbitrary. Thus, it appears that the arithmetical divi- n of the scale, and consequently the thermometric unit, the ition of its zero, and, in fine, the standard temperatures by ich alone the indication of different thermometers can be ren- ed comparable, are severally arbitrary. Unanimity, neverthe- s, has prevailed in the selection of standard temperatures. The nperature at which ice melts, and that at which distilled water ls, when the barometer stands at 29·8 inches, have been adopted in all countries as the two temperatures with reference to which thermometric scales are constructed.



Fig. 223.

327. The bulb and tube, as already described, being filled with pure mercury, and a blank scale being attached to the tube, the instrument is immersed successively in melting ice and boiling water, and the points at which the mercurial column stands in each case are marked upon the scale. The former is called the *freezing point*, and the latter the *boiling point.*

To determine the freezing point, the bulb and tube are placed in a vessel of sufficient depth, such as that shown in *fig.* 223., and surrounded with pounded ice, a hole being left in the bottom, from which the water proceeding from the fusion of the ice is discharged. By this angement, the entire quantity of mercury included in the bulb d tube must necessarily be reduced to the exact temperature of lting ice. When the summit of the mercurial column in the be is observed to become stationary, its position is marked on e glass by a diamond point. This will be, therefore, the freez- g point of the thermometer.

To determine the boiling point, the thermometer is in like manner immersed in a reservoir of steam, proceeding from boiling water when the barometer stands at 29·8 inches.

The manner in which this process is conducted is shown in *fig*. 224., where D is the boiler placed over a charcoal furnace F, shown in section in *fig*. 225. From the top of the boiler a tube

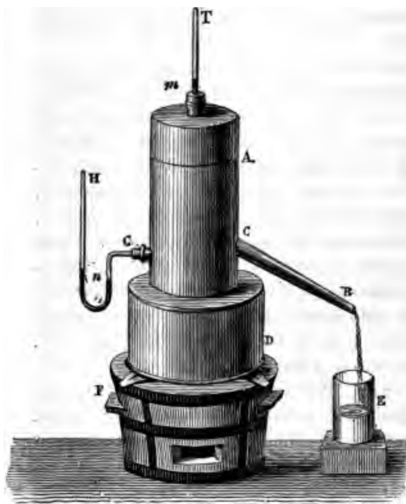


Fig. 224.

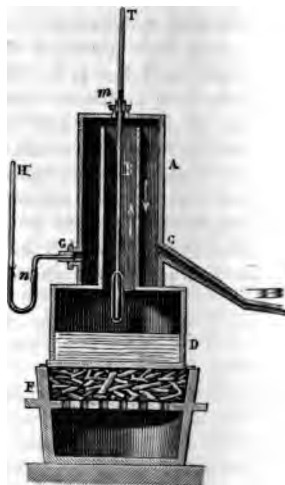
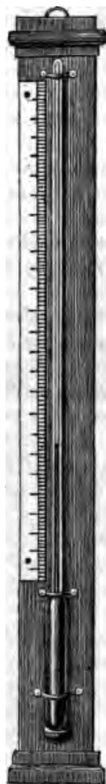


Fig. 225.

proceeds, open at the top, which is enveloped in another, A, closed at the top and soldered at the bottom to the top of the boiler. In the external tube A there are three openings, in one of which, *m*, the tube of the thermometer T is inserted. In another, a siphon mercurial gauge G H, and, in the third a discharge tube C B is inserted. When the water boils, the steam rises, surrounding the bulb and tube, and, descending between the two tubes, issues from the discharge pipe B. If the steam be generated too rapidly in the boiler, it will press on the mercury in the gauge, which will then stand at a higher level *n* in the ascending than in the descending leg. In that case, the pressure of the steam will be greater than that of the atmosphere, and the force of the furnace must be moderated until the level of the mercury in the two legs of the siphon coincide, when the pressure of the steam will be exactly equal to that of the atmosphere.

It will be explained hereafter that the boiling temperature of water rises and falls with every increase and decrease of the height of the barometric column; and it has consequently been necessary,

in fixing the conventional standard of the boiling point, to assign at the same time the corresponding height of the barometer; such conventional height being its mean altitude in these climates.


Fig. 226.

In the experimental determination of the boiling point, however, the desired result may be obtained, whatever may be the height of the barometer, by allowing one degree of temperature, above or below the standard boiling point, for every sixth of an inch in the barometric column above or below the standard altitude of 29·8 inches.

328. **Fahrenheit's scale.**— The same unanimity has not prevailed either as respects the unit or the thermometric zero. In England, Holland, some of the German States, and in North America, the interval between the freezing and boiling points is divided into 180 equal parts, each part representing the thermometric unit. The scale is continued by equal divisions above the boiling and below the freezing points. The zero is placed at the thirty-second division below the freezing point; so that, on this scale, the freezing point is $32°$, and the boiling point $32°+180°=212°$. This scale is known as Fahrenheit's, and was adopted about 1724.

The reason for fixing the zero of the scale at $32°$ below the freezing point is, that that point indicated a temperature which was at that time believed to be the natural zero of temperature, or the greatest degree of cold which could exist, being the most intense cold which had been observed in Iceland.

We shall see hereafter that much lower temperatures, natural and artificial, have been since observed.

The divisions of the interval between the freezing and boiling points into 180 equal parts was founded upon some inexact supposition connected with the dilatation of mercury. The divisions of this scale are continued in the same manner below zero, such divisions being considered negative, and expressed by the negative sign prefixed to them. Thus, $+32°$ signifies $32°$ above zero, but $-32°$ signifies $32°$ below zero.

Centigrade scale. — In France, Sweden, and some other parts of Europe, the centigrade scale prevails.

In this scale the interval between the freezing and boiling points is divided into 100 equal parts, and the zero is placed at the freezing point.

329. **Reaumur's scale.** — In some countries the scale of Reaumur is used, in which the interval between the freezing and boiling points is divided into eighty equal parts, the zero being placed at the freezing point.

330. **Comparative table of the scales.** — Since the numbers of degrees into which the interval between the freezing and boiling points is divided on the three scales are 180, 100, and 80 respectively, it follows that 9° Fahrenheit, 5° centigrade, and 4° Reaumur are represented by equal lengths. Hence are inferred the following rules: —

I. To reduce any number of Fahrenheit degrees to an equivalent number of centigrade or Reaumur degrees, divide by 9, and multiply by 5 for centigrade, and by 4 for Reaumur.

II. To reduce any number of centigrade degrees to an equivalent number of Fahrenheit or Reaumur, divide by 5, and multiply by 9 for Fahrenheit, and by 4 for Reaumur.

III. To reduce any number of Reaumur degrees to an equivalent number of Fahrenheit or centigrade, divide by 4, and multiply by 9 for Fahrenheit, and by 5 for centigrade.

By the following table, computed by the above rules, the corresponding temperatures on these scales may be found: —

Cent.	Reau.	Fahr.	Cent.	Reau.	Fahr.	Cent.	Reau.	Fahr.	Cent.	Reau.	Fahr.
100	80·	212·	64	51·2	147·2	29	23·2	84·2	—6	—4·8	21·2
99	79·2	210·2	63	50·4	145·4	28	22·4	82·4	7	5·6	19·4
98	78·4	208·4	62	49·6	143·6	27	21·6	80·6	8	6·4	17·6
97	77·6	206·6	61	48·8	141·8	26	20·8	78·8	9	7·2	15·8
96	76·8	204·8	60	48·	140·	25	20·	77·	10	8·	14·
95	76·	203·	59	47·2	138·2	24	19·2	75·2	11	8·8	12·2
94	75·2	201·2	58	46·4	136·4	23	18·4	73·4	12	9·6	10·4
93	74·4	199·4	57	45·6	134·6	22	17·6	71·6	13	10·4	8·6
92	73·6	197·6	56	44·8	132·8	21	16·8	69·8	14	11·2	6·8
91	72·8	195·8	55	44·	131·	20	16·	68·	15	12·	5·
90	72·	194·	54	43·2	129·2	19	15·2	66·2	16	12·8	3·2
89	71·2	192·2	53	42·4	127·4	18	14·4	64·4	17	13·6	1·4
88	70·4	190·4	52	41·6	125·6	17	13·6	62·6	18	14·4	—0·4
87	69·6	188·6	51	40·8	123·8	16	12·8	60·8	19	15·2	2·2
86	68·8	186·8	50	40·	122·	15	12·	59·	20	16·	4·
85	68·	185·	49	39·2	120·2	14	11·2	57·2	21	16·8	5·8
84	67·2	183·2	48	38·4	118·4	13	10·4	55·4	22	17·6	7·6
83	66·4	181·4	47	37·6	116·6	12	9·6	53·6	23	18·4	9·4
82	65·6	179·6	46	36·8	114·8	11	8·8	51·8	24	19·2	11·2
81	64·8	177·8	45	36·	113·	10	8·	50·	25	20·	13·
80	64·	176	44	35·2	111·2	9	7·2	48·2	26	20·8	14·8
79	63·2	174·2	43	34·4	109·4	8	6·4	46·4	27	21·6	16·6
78	62·4	172·4	42	33·6	107·6	7	5·6	44·6	28	22·4	18·4
77	61·6	170·6	41	32·8	105·8	6	4·8	42·8	29	23·2	20·2
76	60·8	168·8	40	32·	104·	5	4·	41·	30	24·	22·
75	60·	167·	39	31·2	102·2	4	3·2	39·2	31	24·8	23·8
74	59·2	165·2	38	30·4	100·4	3	2·4	37·4	32	25·6	25·6
73	58·4	163·4	37	29·6	98·6	2	1·6	35·6	33	26·4	27·4
72	57·6	161·6	36	28·8	96·8	1	0·8	33·8	34	27·2	29·2
71	56·8	159·8	35	28·	95·	0	0·	32·	35	28·	31·
70	56·	158·	34	27·2	93·2	—1	—0·8	30·2	36	28·8	32·8
69	55·2	156·2	33	26·4	91·4	2	1·6	28·4	37	29·6	34·6
68	54·4	154·4	32	25·6	89·6	3	2·4	26·6	38	30·4	36·4
67	53·6	152·6	31	24·8	87·8	4	3·2	24·8	39	31·2	38·2
66	52·8	150·8	30	24·	86·	5	4·	23·	40	32·	40·
65	52·	149·									

331. **Rate of dilatation of mercury.**—It has been ascertained by experiment, that mercury, when raised from 32° to 212°, suffers an increment of volume amounting to 2-111ths of its volume at 32°. Thus, 111 cubic inches of mercury at 32° will, if raised to 212°, become 113 cubic inches. From this may be deduced the increment of volume which mercury receives for each degree of temperature. For, since the increase of volume corresponding to an elevation of 180° is $\frac{2}{111}$ of its volume at 32°, we shall find the increment of volume corresponding to one degree by dividing $\frac{2}{111}$ by 180, or, what is the same, by dividing $\frac{1}{111}$ by 90, which gives $\frac{1}{9990}$. It follows, therefore, that for each degree of temperature by which the mercury is raised, it will receive an increment of volume amounting to the 9990th part of its volume at 32°. It follows, therefore, that the weight of mercury which fills the portion of a thermometric tube representing one degree of temperature, will be the 9990th part of the total weight contained in the bulb and tube.

In adopting the dilatation of mercury as a measure of temperature, it is assumed that equal dilatations of this fluid are produced by equal increments of heat. Now, although it is certain that to raise a given quantity of mercury from the freezing to the boiling point will always require the same quantity of heat, it does not follow that equal increments of volume will correspond to equal increments of heat throughout the whole extent of the thermometric scale. Thus, although the same quantity of heat must always be imparted to the mercury contained in the tube to raise it from 32° to 212°, it may happen that more or less heat may be required to raise it from 32° to 42°, than from 202° to 212°. In other words, the dilatation produced by equal increments of heat, in different parts of the scale, might be variable. Experiments conducted, however, under all the conditions necessary to ensure accurate results, have proved that mercury is uniformly dilated between the freezing and boiling points, or that equal increments of heat imparted to it produce equal increments of volume. The same uniform dilatation prevails to a considerable extent of the scale above the boiling and below the freezing points; but at extreme temperatures this uniformity of expansion ceases, as will be more fully explained hereafter.

332. **Standard thermometer.** — A thermometer, having once been carefully graduated, may be used as a standard instrument for graduating other thermometers, just as good chronometers, once accurately set, are used as regulators for other time-pieces. To graduate a thermometer by means of such a standard, it is only necessary to expose the two instruments to the same varying temperatures, and to mark upon the blank scale of that which is to be

graduated two points corresponding to any two temperatures shown by the standard thermometer, and then to divide the scale accordingly.

Thus, for example, if the two instruments be immersed in warm water and the column of the standard thermometer be observed to indicate the temperature of 150°, let the point at which the mercury stands in the other thermometer be marked upon its scale.

Let the two instruments be then immersed in cold water, and let us suppose that the standard thermometer indicates 50°. Let the point at which the instrument to be graduated stands be then marked. Let the intervals of the scale between these two points, thus corresponding to the temperatures of 50° and 150°, be divided into one hundred equal parts; each part will be a degree in the scale, which may be continued by like divisions above 150° and below 50°.

333. The range of the scale of thermometers is determined by the purpose to which they are to be applied. Thus, thermometers intended to indicate the temperature of dwelling-houses need not range above or below the extreme temperatures of the air, and the scale does not usually extend much below the freezing point nor above 100°; and thus the sensitiveness of the instrument may be increased, since a considerable length of the tube may represent a limited range of the scale.

334. Mercury possesses several thermal qualities which render it a convenient fluid for common thermometers. It is highly sensitive to change of temperature, dilating with promptitude by the same increments of heat with great regularity and through a considerable range of temperature. It will be shown hereafter that a smaller quantity of heat produces in it a greater dilatation than in most other liquids. It freezes at a very low and boils at a very high temperature. At the temperatures which are not near these extreme limits, it expands and contracts with considerable uniformity.

The freezing point of mercury being—40°, or 40° below zero, and its boiling point + 600°, such a thermometer will have correct indications through a very large range of temperature.

335. It has been found that, from some physical causes which are not satisfactorily explained, the bulbs of thermometers are liable to a change of magnitude after the lapse of a certain time. It follows from this that a thermometer, though accurately graduated when first made, may become at a later period erroneous in its indications; since a diminution of the capacity of the bulb would cause the standard points and all other temperatures to be raised upon the scale. To obviate this, thermometers used for

purposes requiring much precision ought to be verified from time to time by comparison with well-constructed standards, or by exposure to the standard temperatures.

It is also found that a change of magnitude is produced in the bulb of a thermometer by sudden changes of temperature, which render verification necessary.

336. **Self-registering thermometers.** — It is sometimes needed, in the absence of an observer, to ascertain the variations which may have taken place in a thermometer. Instruments called self-registering thermometers have been contrived, which partially serve this purpose by indicating, not the variations of the mercurial column, but the limits of its play within a given time. This is accomplished by floating indices placed on the mercury within the tube, which are so adapted that one is capable of being raised with the column, but not depressed, and the other of being depressed but not raised. The consequence is, that one of these indices will remain at the highest, and the other at the lowest point which the mercurial column may have attained in the interval, and thus register the highest point and lowest point of its range.

The self-registering thermometers on this principle which are the best known are Sykes and Rutherford's.

337. **Rutherford's thermometer.** — This instrument consists of two tubes attached in a horizontal position to a plate of glass, as shown in *fig.* 227., being bent at right angles near the bulbs.

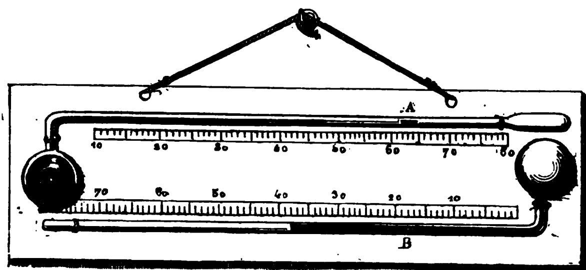


Fig. 227.

The one, A, contains mercury; the second, B, alcohol. In the tube of the former is a small piece of iron wire which moves in it freely, being pushed along by the mercury as it expands. When the tube is placed in the vertical position, with the mercurial bulb downwards, the iron wire falls upon the mercury; and when in

the horizontal position, being pushed to the right by the expansion of the mercury, it will remain at the most extreme point to which the mercury may have moved it, and will not follow the mercury in its contraction. It will thus remain as an indication of the highest temperature to which the instrument has been exposed.

The tube of the alcohol thermometer contains, in like manner, a small piece of coloured glass, having a knob at each end; this allows the alcohol to pass it freely from right to left. But when the alcohol contracts, and moves towards the bulb, it carries with it the glass index B, which, consequently, remains in whatever position is given to it when the thermometer has been exposed to the lowest temperature. Thus, while A shows the *maximum*, B shows the *minimum* temperature to which the instrument has been exposed.

338. **Negretti's thermometer.** — This is a modification of the former, and is intended to remedy the inconvenience which arises from the liability of the iron wire to pass below the surface of the mercury, by the accidental agitation of the instrument. The instrument is shown in *fig.* 228. Having introduced into the tube

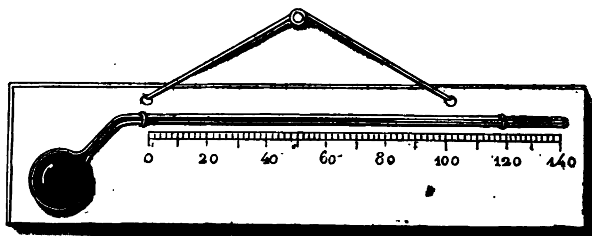


Fig. 228.

a little rod of glass, the tube is softened with a blowpipe, and slightly bent at the place where the glass rod stands, so that it becomes fixed in the tube, leaving, nevertheless, sufficient space around it for the mercury to pass. Supposing, then, the instrument to be suspended with the tube horizontal, as shown in the figure, and exposed to an increase in the temperature, the mercury, by expanding, will force its way past the angle; but when the temperature falls, the mercury which has passed the angle will not return to the bulb, since it exerts no force to carry it round the angle. The extremity of the column will therefore indicate the highest temperature to which the instrument has been exposed.

339. **Walferdin's thermometer.** — This instrument, which is represented in *fig.* 229., consists of a tube, at the top of which there is a small reservoir to receive the mercury, which overflows by expansion. When it is required to prepare the instrument for use, it is inverted, so that the extremity of the tube will be immersed in the mercury contained in the upper reservoir then turned downwards. The instrument, in this inverted position, is exposed to a temperature lower than any to which it will be subject in the observations about to be made. The instrument is then restored to its proper position, when the tube will be full to the top. As the temperature to which it is exposed rises, the mercury, by its expansion, is forced out of the tube, and discharged from its point into the upper reservoir; and this discharge continues until the temperature reaches its maximum height, after which the mercury contracts, and the column falls in the tube.

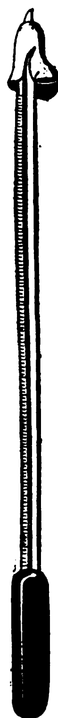


Fig. 229.

To determine the highest temperature to which the instrument has been exposed, it will be only necessary to compare it with another thermometer, immersing both in the same bath, until the column rises to the summit of the tube. The temperature then indicated by the standard thermometer, will be that to which the thermometer has been exposed.

Walferdin has also constructed thermometers to register the minimum temperature, but they are not so convenient as the others above described.

340. **Spirit of wine thermometers.** — Alcohol is frequently used as a thermoscopic liquid. It has the advantage of being applicable to a range of temperature below the freezing point of mercury; no degree of cold yet observed in nature or attained by artificial processes having frozen it. It is usually coloured so as to render the column easily observable in the tube.

341. **Air thermometers.** — Atmospheric air is a good thermoscopic fluid. It has the advantage over liquids in retaining its gaseous state at all temperatures, and in the perfect uniformity of its dilatation and contraction. It is also highly sensitive, indicating changes of temperature with great promptitude. Since, however, it is not visible, its expansion and contraction must be rendered observable by expedients which interfere with and render complicated its indications.

342. **Drebbel's thermometer.** — The air thermometer of Drebbel, or, according to some, of Sanctorius, is represented in



Fig. 230.

fig. 230. A glass tube A B, open at one end, and having a large thin bulb C at the other, is placed with its open end in a coloured liquid, so that the air contained in the tube shall have a less pressure than the atmosphere. A column of the liquid will therefore be sustained in the tube A B, the weight of which will represent the difference between the pressure of the external air and the air enclosed in the tube.

If the bulb C be exposed to a varying temperature, the air included in it will expand and contract, and will cause the column of coloured liquid in the tube A B to rise and fall, thereby indicating the changes of temperature.

343. **Amonton's thermometer.** — Another form of air thermometer is represented in *fig.* 231. The air included fills half the capacity of the bulb C, and its expansion and contraction cause the coloured liquid to rise or fall in the tube A B.



Fig. 231.

344. **Differential thermometer.** — Of all forms of air thermometer, that which has proved of greatest use in physical inquiries is the differential thermometer represented in *figs.* 232. and 233. This consists of two glass bulbs, A and B, connected by a rectangular glass tube. In the horizontal part of the tube a small quantity of coloured liquid (sulphuric acid, for example) is placed. Atmospheric air is contained in the bulbs and tube, separated into two parts by the liquid. The instrument is so adjusted that when the drop of liquid is at the

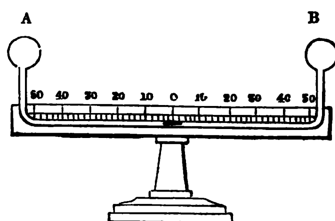


Fig. 232.

middle of the horizontal tube, the air in the bulbs has the same pressure; and, having equal volumes, the quantities at each side of the liquid are necessarily equal. If the bulbs be affected by different temperatures, the liquid will be pressed from that side at which the temperature is greatest, and the extent of its departure from the zero or middle is indicated by the scale.

This thermometer is sometimes varied in its form and arrangement, but the principle remains the same.

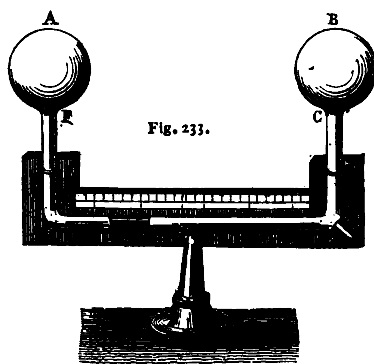


Fig. 233.

Its extreme sensitiveness, in virtue of which it indicates changes of temperature too minute to be observed by common thermometers, renders it extremely valuable as an instrument of scientific research.

By this instrument, changes of temperature not exceeding the 6000th part of a degree are rendered sensible.

345. **Breguet's metallic thermometer.** — This instrument, founded upon the unequal dilatation of different metals, is represented in *fig.* 234. Three very thin strips of platinum, gold, and silver, being soldered face to face, are formed into a spiral or helix. Having fixed the upper extremity of this to a support, a light needle is attached at right angles to the helix at the lower end. According as the metal of the helix expands and contracts, the lower extremity to which the needle is attached will move round a spiral, and the needle will consequently revolve like the hand of a watch. A graduated circle, like the dial of a watch, is placed under it to indicate its motions. The silver, which is the most dilatable of the three metals, forms the inner face of the helix, and the platinum, which is the least dilatable, the outer; the

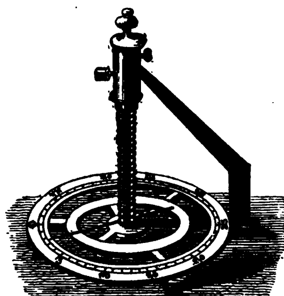


Fig. 234.

gold being included between them. When the temperature rises, the silver being more dilated than the platinum or gold, the helix unrolls itself; and when the temperature falls, the contrary effect takes place. The needle, therefore, in the two cases is turned in contrary directions. The gold is placed between the two other metals because, having an intermediate dilatability, it moderates their mutual effect. If two metals only were employed, the difference of the dilatations might produce a rupture.

This thermometer is graduated by comparing it with a standard thermometer.

346. **Pyrometers.** — The range of the mercurial thermometer being limited by the boiling point of mercury, higher temperatures are measured by the expansion of solids, whose points of fusion are at a very elevated part of the thermometric scale. The solids which are best adapted for this purpose are the metals. Being good conductors, these are promptly affected by heat, and their indications are immediate, constant, and regular.

Instruments adapted for the indication and measurement of this high range of temperature are called *pyrometers*.

347. To graduate a pyrometer, let the metallic bar be immersed successively in melting ice and boiling water, and let its length at these temperatures be accurately measured. Their difference being divided by 180, the quotient will be the increment of length corresponding to one degree of temperature; and this increment being multiplied, the length corresponding to any proposed temperature may be ascertained.

Let L° express the length of the bar at the temperature 32°.

Let L' express its length at the temperature 212°.

Let i express the increase of length corresponding to 1°.

We shall then have

$$i=\frac{L'-L^\circ}{180}.$$

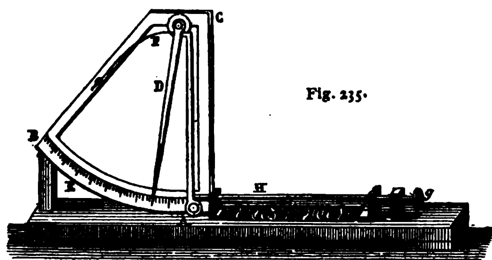
If L express in general the length of the bar at the temperature expressed by T, we shall have

$$L=L^\circ+i\times(T-32),$$

which means nothing more than that the length at the temperature T is found by adding to the length at the temperature 32° as many times the increment corresponding to 1° as there are degrees in T above 32°.

The instrument represented in *fig.* 235. is one of the most simple forms of pyrometer.

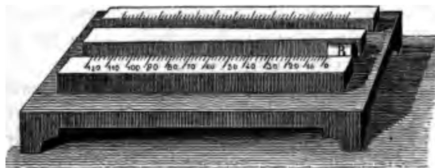
A rod of metal, H, is in contact at one end with the point of a screw *g*, and at the other with a lever A near its fulcrum. This


Fig. 235.

lever is connected with another so as to form a compound system, such that any motion imparted by the rod to the point on the lever A in contact with it is augmented in a high ratio. A lamp placed under the rod H raises its temperature; and, as it is resisted by the point of the screw *g*, its dilatation must take effect against the lever A, which, acting on the second lever D, will move the index on the graduated arc A B. The ratio of this motion to that of the end of the bar acting on the lever being known, the quantity of dilatation may be calculated.

348. **Wedgewood's pyrometer.** — It is found that the paste formed by saturating potter's earth with water, when exposed to high temperatures, instead of being dilated like other solid bodies, is contracted. This apparent exception to the general thermal law is explained by the fact that the increase of temperature evaporates a part of the water, which has given plasticity to the clay, and that the particles of the clay are then brought closer together by their natural cohesion. Whatever be the cause by which this effect is explained, the degree of contraction produced has been considered sufficiently regular to be taken as a measure of the temperature to which the paste has been exposed, and upon this principle Wedgewood's pyrometer is based.

Three bars of copper, each 6 inches long, are fixed upon a plate


Fig. 236.

of metal in juxtaposition, as shown in *fig.* 236., but not exactly parallel. The edges of the first and second bar at one end are

exactly ½ an inch asunder, while at the other end the distance between them is less than ½ an inch by 1 line, or the 12th of an inch. In like manner, the edges of the second and third bars are separated by a space less than ½ an inch by 1 line at one end, and by a space less than ½ an inch by 2 lines at the other end.

A number of small cylinders of potter's earth, exactly ½ an inch in diameter, baked in an oven at the temperature of 212° are provided. These will, therefore, exactly correspond with the interval between the bars of the pyrometer at their widest end. When it is desired to ascertain, for example, the temperature of a furnace, one of these cylinders is placed in it, and after its temperature has been elevated to that of the furnace, it is withdrawn, and allowed to cool; it is then inserted at the widest end of the bars, between which it will now enter in consequence of its contraction. It is advanced between them as far as it will go, as shown in the figure. The bars being graduated, the distance through which it advances shows the extent of its contraction, and this extent is taken as the measure of the temperature which has produced it.

These instruments, however, give results which are attended with several causes of uncertainty, the principal of which is, that the extent of the contraction depends not only on the temperature to which the cylinder has been exposed, but to the length of time during which it has been subject to that temperature.

349. **Brogniart's pyrometer.** — M. Brogniart, while director of the royal porcelain manufactory at Sèvres, constructed a pyrometer similar in principle to that shown in *fig.* 235., consisting of a bar of iron or platinum placed within the oven, one end being fixed, and the other acting upon a rod of porcelain which presses against the compound lever, so as to move the index and show the expansion.

350. **Dilatation of metallic measures.** — The standards used as measures of length for ascertaining distances where great accuracy is required, such as in measuring the bases in geographical surveys, are usually rods of metal. But since these are subject to a change of length with every change of temperature, it would follow that the results of any measurement made by them would be attended with corresponding errors.

For the common purposes of domestic and commercial economy, such errors are too trifling to be worth the trouble of correcting; but this is not the case when they are applied to scientific purposes. It is necessary in such cases to observe the temperature of the rods at the moment each measurement is made.

351. **Borda's pyrometric standard measure.** — In the operation by which the great arc of the meridian in France was measured, a very beautiful expedient was contrived by Borda, in which

the bar itself is converted into a thermometer which indicates its own temperature. This expedient was again rendered available for the series of experiments made by Dulong and Petit, to ascertain the dilatation of bodies by heat.

A bar of platinum, P P′, *fig.* 237., was connected at one extremity with a similar bar of brass B B′, of very nearly equal length.

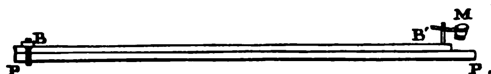


Fig. 237.

The two bars, being screwed or rivetted together at the extremity B, were free at every other point. Near the extremity P′ of the bar of platinum, and immediately under the extremity B′ of the brass bar, a very exact scale was engraved, the divisions of which marked the millionth part of the entire length of the rod. The extremity B′ of the brass bar carried an index, which moved upon the divided scale. Over the point of this was placed a microscope M, by which its position could be ascertained, and by which the divisions of the scale could be more exactly read off.

If the two bars, P P′ and B B′, were equally dilatable, it is evident that the same change of temperature affecting both would make no change in the position of the index; but, brass being more dilatable than platinum, the index pushed by the expansion of the bar B B′ would be moved towards P′ through a space greater than that by which the bar P P′ would be lengthened, and, consequently it would be advanced upon the scale through a space equal to the difference between the dilatation of the two bars.

The manner of graduating the scale upon P P′ was as follows. The compound bar being submerged in a bath of melting ice, the position of the index was observed. It was then transferred to a bath of boiling water, when the position of the index was again observed.

The interval between these two positions being divided into 180 equal parts, each part would represent one degree of temperature; or, if such division were too minute to be practicable, it might be divided into a less number of equal parts, as, for example, 36, in which case each division would correspond to 5°. When the index, as most frequently happens, stands between two divisions of the scale, it is necessary to estimate or measure its distance from one of these divisions, in order to express its exact position. This is accomplished by the contrivance called a *vernier*, which has been already described in its application to barometers (229.).

CHAP. III.

DILATATION.

352. **Solids.** — Of all the states of aggregation of matter, that in which it is least susceptible of dilatation is the solid state. This may be explained by the energy of the cohesion of the component particles of the body, which is the characteristic property of the solid state. It is the nature of heat, by whatever hypothesis that agency be explained, to introduce a repulsive force among the molecules of the body it pervades. In solid bodies this repulsive force, acting against the cohesive force, diminishes the tenacity of the body. The component parts have a tendency to separate from each other, and hence arises the phenomenon of dilatation; but so long as the body preserves the character of solidity, the separation of the component molecules cannot exceed the limits of the play of the cohesive principle; and as these limits are very small, no dilatation which is consistent with the character of a solid can be considerable.

353. If a solid body be perfectly homogeneous, it will dilate uniformly throughout its entire volume by an uniform elevation of temperature. Thus, the length, breadth, and depth will, in general, be all augmented in the same proportion.

354. It is a principle of geometry, that when a solid body, without undergoing any change of figure, receives a small increase of magnitude, its increase of surface will be twice, and its increase of volume thrice, the increase of its linear dimensions. That is to say, if its length be augmented by a thousandth part of its primitive length, its surface will be augmented by *two* thousandth parts of its primitive surface, and its volume by *three* thousandth parts of its primitive volume. This is not true in a strictly mathematical sense, but it is sufficiently near the truth for all practical purposes.

Now, since all solid bodies of uniform structure, when affected by heat, expand or contract without suffering any change of figure, and since, while the change of their linear dimensions can be easily and exactly ascertained, that of their surface or volume would be determined with much more difficulty, the changes of these last are deduced from the first by multiplying it by 2 for the increment of surface, and by 3 for the increment of volume.

Thus, if it be found that a bar of zinc being raised from 32° to 212°, receive an increment of length equal to the 340th part of its length at 32°, it may be inferred that its increment of surface

is *two* 340th parts, and that its increment of volume is *three* 340th parts of its volume at 32°.

355. It is found that solid bodies in general suffer an uniform rate of dilatation, through a range of temperature extending from 32° to 212°; that is to say, the increments of volume which attend each degree of temperature which the body receives are equal. If, therefore, the entire increment of volume which such a body undergoes when it is raised from 32° to 212° be divided by 180, the quotient will be the increment of volume which it receives when its temperature is raised one degree.

356. When solids are elevated to temperatures much above 212°, and more especially when they approach those temperatures at which they would be fused or liquefied, the dilatations are not uniform. As the temperature is raised, the rate of dilatation is increased; that is to say, a greater increment of volume attends each degree of temperature.

357. There are also certain exceptional cases in some crystallised bodies, in which, notwithstanding they are homogeneous, the dilatation is not equal in all their dimensions. Certain crystals are found to suffer more dilatation in the direction of one axis than in the direction of another.

358. **Table of the dilatation of solids.** — In the following table are given the rates of dilatation of solid bodies according to the most recent and accredited authorities: —

Bodies.	Dilatation in Fractions.	
	Decimal.	Vulgar.
Dilatation from 32° to 212°, according to Lavoisier and Laplace.		
Flint glass (English) -	0·00081166	1/1232
Platinum (according to Borda) - - - -	0·00085655	1/1167
Glass (French) with lead -	0·00087199	1/1147
Glass tube without lead -	0·00087572	1/1142
Ditto - - - - -	0·00089694	1/1115
Ditto - - - - -	0·00089760	1/1114
Ditto - - - - -	0·00091750	1/1090
Glass (St. Gobain) - -	0·00089089	1/1122
Steel (untempered) - -	0·00107880	1/927
Ditto - - - - -	0·00107915	1/927
Ditto - - - - -	0·00107960	1/926
Steel (yellow temper) at 65°	0·00123956	1/807
Iron, soft forged - -	0·00122045	1/819
Iron, round wire-drawn -	0·00123504	1/810
Gold - - - - -	0·00146606	1/682
Gold (French standard) annealed - - -	0·00151361	1/661
Gold (ditto) not annealed	0·00155155	1/645
Copper - - - -	0·00171220	1/584
Ditto - - - - -	0·00171733	1/582
Ditto - - - - -	0·00172240	1/581
Brass - - - -	0·00186670	1/535
Ditto - - - - -	0·00187821	1/532
Ditto - - - - -	0·00188970	1/529
Silver (French standard) -	0·00190868	1/524
Silver - - - -	0·00190974	1/524
Tin, Indian - - -	0·00193765	1/516
Tin, Falmouth - - -	0·00217298	1/460
Lead - - - - -	0·00284836	1/351
According to Smeaton.		
Glass, white (barometer tubes) - -	0·00083333	1/1200
	0·00108333	1/923
Steel - - - - -	0·00115000	1/870
Steel tempered - - -	0·00122500	1/816
Iron - - - - -	0·00125833	1/795
Bismuth - - - -	0·00139167	1/719

Bodies.		Dilatation in Fractions. Decimal.	Vulgar.
Copper - - - -		0 00170000	$\frac{1}{588}$
Copper 8 parts, tin 1 -		0·00181667	$\frac{1}{550}$
Brass cast - - -		0·00187500	$\frac{1}{533}$
Brass 16 parts, tin 1 - -		0·00190833	$\frac{1}{524}$
Brass wire - - - -		0·00193333	$\frac{1}{517}$
Telescope speculum metal		0 00193333	$\frac{1}{517}$
Solder (copper 2 parts, zinc 1) - - - -		0·00205833	$\frac{1}{486}$
Tin (fine) - - - -		0·00228333	$\frac{1}{438}$
Tin (grain) - - -		0·00248333	$\frac{1}{403}$
Solder white (tin 1 part lead 2) - - - -		0·00250533	$\frac{1}{399}$
Zinc 8 parts, tin 1, slightly forged - - -		0·00269167	$\frac{2}{372}$
Lead - - - - -		0·00286667	$\frac{1}{349}$
Zinc - - - - -		0·00294167	$\frac{1}{340}$
Zinc lengthened $\frac{1}{12}$ by hammering - - - -		0·00310833	$\frac{1}{322}$
Palladium (*Wollaston*) -		0·00100000	$\frac{1}{1000}$
According to Dulong and Petit.			
Platinum -	32° to 212°	0·00088420	$\frac{1}{1131}$
	32° to 572°	0·00275482	$\frac{1}{363}$

Bodies.		Dilatation in Fractions. Decimal.	Vulgar.
Glass -	32° to 212°	0·00086133	$\frac{1}{1161}$
	32° to 392°	0·00184502	$\frac{1}{542}$
	32° to 572°	0 00303252	$\frac{1}{329}$
Iron - -	32° to 212°	0·00118210	$\frac{1}{846}$
	32° to 572°	0·00440528	$\frac{1}{227}$
Copper -	32° to 212°	0·00171820	$\frac{1}{582}$
	32° to 572°	0·00564972	$\frac{1}{177}$
According to Troughton.			
Platinum - - - -		0·00099180	$\frac{1}{1008}$
Steel - - - -		0·00118990	$\frac{1}{840}$
Steel wire drawn - -		0 00144010	$\frac{1}{694}$
Copper - - - -		0·00191880	$\frac{1}{521}$
Silver - - - -		0·00208260	$\frac{1}{480}$
From 32° to 217°, according to Roy.			
Glass (tube) - - -		0·00077550	$\frac{1}{1289}$
Glass (solid rod) - -		0·00080833	$\frac{1}{1237}$
Glass cast (prism of) -		0 00111000	$\frac{1}{901}$
Steel (rod of) - - -		0·00114450	$\frac{1}{874}$
Brass (Hamburg) - -		0·00185550	$\frac{1}{539}$
Brass (English) rod - -		0·00189296	$\frac{1}{528}$
Brass (English), angular -		0·00189450	$\frac{1}{528}$

359. **Measure of the force of dilatation.** — The force with which solid bodies dilate and contract is equal to that which would compress them through a space equal to their dilatation, and to that which would stretch them through a space equal to the amount of their contraction. Thus, if a pillar of metal one hundred inches in height, being raised in temperature, is augmented in height by a quarter of an inch, the force with which such increase of height is produced is equal to a weight which being placed upon the top of the pillar would compress it so as to diminish its height by a quarter of an inch.

In the same manner, if a rod of metal, one hundred inches in length, be contracted by diminished temperature, so as to render its length a quarter of an inch less, the force with which this contraction takes place is equal to that which being applied to stretch it would cause its length to be increased by a quarter of an inch.

360. **Examples.** — This principle is often practically applied in cases where great mechanical force is required to be exerted through small spaces. Thus, in cases where the walls of a building have been thrown out of the perpendicular, either by the unequal subsidence of the foundation or by the incumbent pressure of the

roof, they have been restored to the perpendicular by the following arrangement:—

A series of iron rods are carried across the building, passing through holes in the walls, and are secured by nuts on the outside. The alternate bars are then heated by lamps until they expand, when the nuts, which are thus removed to some distance from the walls by the increased length of the bars, are screwed up so as to be in close contact with them. The lamps are then withdrawn, and the bars allowed to cool. In cooling they gradually contract, and the walls are drawn together by the nuts through a space equal to their contraction. Meanwhile, the intermediate bars have been heated and expanded, and the nuts screwed up as before. The lamps being again withdrawn and transferred to the first set of bars, the second set are contracted in cooling, and the walls further drawn together. This process is continually repeated, until at length the walls are restored to their perpendicular position.

361. In all cases where moulds are constructed for casting objects in metal, the moulds must be made larger than the intended magnitude of the object, in order to allow for its contraction in cooling. Thus the moulds for casting cannon balls must always be greater than the calibre of the gun, since the magnitude of the mould will be that of the ball when the metal is incandescent, and therefore greater than when it is cold.

362. Hoops surrounding water-vats, tubs, and barrels, and other vessels composed of staves, and the tires surrounding wheels, are put on in close contact at a high temperature, and, cooling, they contract and bind together the staves or fellies with greater force than could be conveniently applied by any mechanical means.

363. **Compensators.**—In all structures composed of metal, or in which metal is used in combination with other materials, such as roofs, conservatories, bridges, railings, pipes for the conveyance of gas or water, rafters for flooring, &c., compensating expedients must be introduced, to allow the free play of the metallic bars in dilating and contracting with the vicissitudes of temperature, to which they are exposed during the change of seasons.

These expedients vary with the way in which the metal is applied, and with the character of the structure. Pipes are generally so joined from place to place as to be capable of sliding one within another, by a telescopic joint. The successive rails which compose a line of railways cannot be placed end to end, but space must be left between their extremities for dilatation.

364. **Metal roofs.** — Sheet lead and zinc, both of which metals are very dilatable, when used to cover roofs, where they are espe-

cially exposed to vicissitudes of temperature, are liable to blister in hot weather by expansion and to crack in cold weather by contraction, unless expedients are adopted to obviate this: zinc, being much more dilatable than lead, is more liable to these objections.

365. When ornamental furniture is inlaid with metal without providing for its expansion, the metal, being more dilatable than the wood, is liable, in a small room, to expand and start from its seat.

366. **Compensating pendulum.**—The application of compensators to the pendulums of clocks has been already explained ("Mechanics," 673.).

367. **Dilatation of gases.**—It has been already shown (213.), that the dimensions of bodies in the gaseous state are dependent altogether upon the pressure by which they are confined. They are capable of expanding spontaneously into any dimensions, however great, and of being reduced by greater pressure to any volume, however small. It follows, therefore, that whenever it is required to determine the change of dimensions of gaseous bodies produced by change of temperature, it will be necessary to provide means of keeping them during the experiment under a uniform pressure, since otherwise the change of dimensions due to change of pressure would be combined with that which is due to change of temperature.

368. Experimental inquirers have contrived and practised various expedients to accomplish this, one of the most simple of which is that of M. Pouillet, represented in *fig.* 238. An iron siphon tube D C is formed with short legs, from the bottom of which proceeds a pipe with a stop-cock F, under which is placed a cistern or reservoir G. In the legs of the siphon D C are inserted two glass tubes D E and C B, of more than thirty inches in height. The tube D E is open at the top; the tube C B is closed at the top, but has a horizontal branch united to it at B, which is connected with a tube A B made of platinum, which terminates in a hollow ball A, also of platinum. A stop-cock is provided in the tube B A, so as to communicate at pleasure with the external air. The stop-cock F being closed, and the stop-cock in the tube B A being open, mercury is poured into the tube D E, so as to fill the glass tubes D E and C B nearly to the

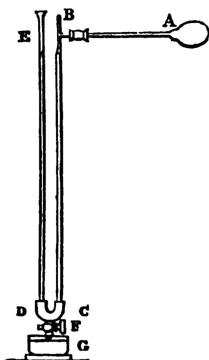


Fig. 238.

top. Since the two tubes D E and C B both communicate with the external air, the columns of mercury in them will stand at the same level. To determine the expansion which air suffers when raised from the freezing to the boiling point under a uniform pressure, let the reservoir A be immersed in a bath of melting ice, so as to reduce the air included in it to the freezing point. Let the stop-cock in the tube B A be then closed, and let the bulb A be removed to a bath of boiling water. The air in the bulb, expanding, will press down the column of mercury in B C, and will cause the column in D E to rise; so that the levels of the two columns will no longer coincide. But they may be equalised by opening the stop-cock F, and allowing mercury to flow into the reservoir G from the siphon, until the levels in the two legs come to the same point. When that is accomplished, the pressure upon the expanded air included in the bulb A, and the tube communicating with it, will be equal to that of the atmosphere, and equal to that which the same air has when at the freezing point.

The capacity of the tube C B being known, the volume which corresponds to any length of it will be also known.

Now the increment of volume which the air has suffered by expansion will be indicated by the height through which the mercury has fallen in the tube C B. This increment, therefore, will be the dilatation of the air included in the bulb A and the communicating tube, between the freezing and boiling points.

In the same manner, by this apparatus, the dilatation corresponding to any change whatever of temperature under a given pressure can be ascertained.

369. It has been proved by experiments made with this as well as a variety of other apparatus adapted to the same purpose, that the dilatation of all bodies in the gaseous form is perfectly uniform throughout the whole extent of the thermometric scale, the same increments of temperature producing, under the same pressure, equal increments of volume. But, what is still more remarkable, it has been found that all gases whatever, as well as all vapours raised from liquids by heat, are subject to exactly the same quantity of expansion by the same change of temperature.

370. By the experiments of M. Gay Lussac, it was demonstrated in 1804, that 1000 cubic inches of atmospheric air raised from the freezing to the boiling point were dilated so as to make 1375 inches. These experiments have more recently been repeated by MM. Rudberg, Magnus, Regnault, and Pouillet. It has been found that the dilatation is more exactly expressed by 1367 cubic inches. Thus the increment of volume of atmospheric air between 32° and 212° is the $\frac{367}{1000}$th, or more than one third of its volume at 32°. It follows, therefore, that ten cubic inches of

atmospheric air at 32° will, if raised to the temperature of 212°, become, by dilatation, nearly $13\frac{7}{10}$ cubic inches; and, for every additional 180° of temperature which it receives, it will undergo a like increase of volume.

371. To find the increment of volume corresponding to one degree of temperature, we have only to divide the fraction $\frac{367}{1000}$ by 180, which gives $\frac{367}{180000}=\frac{1}{490}$.

The increment of volume, therefore, which any gas or vapour undergoes when, under the same pressure, the temperature is raised one degree, is the 490th part of the volume which it would have if reduced to the temperature of 32°.

It follows from this, that if any volume of air at 32° be raised to the temperature of $32°+490°=522°$, it will expand into twice its volume; and if it be raised to a temperature of $32°+2\times490=1012$, it will be expanded into three times its volume; and so on.

372. The well-known experiments of Gay Lussac, the results of which were in accordance with those subsequently obtained by Dulong and Petit, establish the fact that all gases, as well as all vapours, undergo equal changes of volume, by equal increments of temperature, the co-efficient of the expansion of atmospheric air being common to all.

373. Rudberg first called in question the correctness of this principle, and not only showed that the co-efficient of the expansion of atmospheric air previously determined was inexact, but that other gases, though nearly equal in their rates of expansion to each other and to atmospheric air, were not precisely so. These researches of Rudberg have been confirmed by those of Magnus and Regnault; and it appears from them that the following are the increments of volume which the undermentioned gases undergo between 32° and 212°, their volume at 32° being 1·000.

Hydrogen	0·366	Protoxide of azote	0·372
Atmospheric air	0·367	Cyanogen	0·388
Carbonic oxide	0·367	Sulphurous acid	0·390
Carbonic acid	0·371		

M. Regnault also found that the dilatation of the same gases are not exactly the same at all pressures. Thus, under $3\frac{1}{3}$ atmospheres the dilatation of hydrogen remains unvaried, but the dilatation of air increases from 0·367 to 0·369, and that of carbonic acid from 0·371 to 0·385, while the dilatation of sulphurous acid, under a pressure of only one atmosphere, increases from 0·390 to 0·398.

Thus it appears that although it be certain that the gases are subject to a small difference in their rates of dilatation, and also

that the rate of dilatation of the same gas is not absolutely the same at different pressures, yet the inequality and variations are such as may be disregarded for all practical purposes; and it may be assumed that all gases and all vapours dilate uniformly, and in the same degree as atmospheric air.

374. The following formulæ will serve to calculate the change of volume which atmospheric air, or any other gas which dilates equally with it, undergoes for any proposed change of temperature.

Let v express a volume of air at 32°.

Let V express its volume when raised to a temperature which exceeds 32° by a number of degrees expressed by T.

The increment of volume, therefore, corresponding to the increment of temperature expressed by T, will be $V-v$; and since the increment of volume corresponding to 1° is $\frac{v}{490}$, the increment corresponding to T degrees will be $\frac{v}{490}\times T$. We shall therefore have

$$V-v=\frac{v}{490}\times T;$$

and consequently

$$V=\left(1+\frac{T}{490}\right)\times v.$$

In this case the gas has been supposed to be submitted to an increase of temperature. If it be reduced to a lower temperature, it will suffer a decrement of volume, expressed by $v-V$; and if T express the number of degrees below 32° to which it is reduced, the decrement of volume for 1° being $\frac{v}{490}$, the decrement for T degrees will be as before, $\frac{v}{490}\times T$, and we shall have

$$v-V=\frac{v}{490}\times T,$$

from which we find,

$$V=\left(1-\frac{T}{490}\right)\times v.$$

If, therefore, the volume of a gas at 32° be known, its volume at any other temperature above or below 32° may be calculated by the following

RULE.

Divide the difference between the number of degrees in the temperature and 32° by 490. Add the quotient to 1 if the temperature be above 32°, and subtract it from 1 if it be below 32°. Multiply

the volume of the gas at 32° by the resulting number, and the product will be the volume of the gas at the proposed temperature.

Table showing the changes of volume of a gaseous body consequent on given changes of temperature.

In the columns V of the following table are expressed in cubic inches the volumes which a thousand cubic inches of air at 32° will have at the temperatures expressed in the columns T, being supposed to be maintained under the same pressure.

T.	V.	T.	V.	T.	V.	T.	V.	T.	V.
−50	832·7	8	951·0	66	1069·4	124	1187·8	182	1306·1
−49	834·7	9	953·1	67	1071·4	125	1189·8	183	1308·2
−48	836·7	10	955·1	68	1073·5	126	1191·8	184	1310·2
−47	838·8	11	957·1	69	1075·5	127	1193·9	185	1312·2
−46	840·8	12	959·2	70	1077·6	128	1195·9	186	1314·3
−45	842·8	13	961·2	71	1079·6	129	1198·0	187	1316·3
−44	844·9	14	963·3	72	1081·6	130	1200·0	188	1318·4
−43	846·9	15	965·3	73	1083·7	131	1202·0	189	1320·4
−42	849·0	16	967·3	74	1085·7	132	1204·1	190	1322·4
−41	851·0	17	969·4	75	1087·8	133	1206·1	191	1324·5
−40	853·1	18	971·4	76	1089·8	134	1208·2	192	1326·5
−39	855·1	19	973·5	77	1091·8	135	1210·2	193	1328·6
−38	857·1	20	975·5	78	1093·9	136	1212·2	194	1330·6
−37	859·2	21	977·6	79	1095·9	137	1214·3	195	1332·6
−36	861·2	22	979·6	80	1098·0	138	1216·3	196	1334·7
−35	863·3	23	981·6	81	1100·0	139	1218·4	197	1336·7
−34	865·3	24	983·7	82	1102·0	140	1220·4	198	1338·8
−33	867·3	25	985·7	83	1104·1	141	1222·4	199	1340·8
−32	869·4	26	987·8	84	1106·1	142	1224·5	200	1342·9
−31	871·4	27	989·8	85	1108·2	143	1226·5	201	1344·9
−30	873·5	28	991·8	86	1110·2	144	1228·6	202	1346·9
−29	875·5	29	993·9	87	1112·2	145	1230·6	203	1349·0
−28	877·6	30	995·9	88	1114·3	146	1232·7	204	1351·0
−27	879·6	31	998·0	89	1116·3	147	1234·7	205	1353·1
−26	881·6	32	1000·0	90	1118·4	148	1236·7	206	1355·1
−25	883·7	33	1002·0	91	1120·4	149	1238·8	207	1357·1
−24	885·7	34	1004·1	92	1122·4	150	1240·8	208	1359·2
−23	887·8	35	1006·1	93	1124·5	151	1242·9	209	1361·2
−22	889·8	36	1008·2	94	1126·5	152	1244·9	210	1363·3
−21	891·8	37	1010·2	95	1128·6	153	1246·9	211	1365·3
−20	893·9	38	1012·2	96	1130·6	154	1249·0	212	1367·3
−19	895·9	39	1014·3	97	1132·7	155	1251·0	213	1369·4
−18	898·0	40	1016·3	98	1134·7	156	1253·0	214	1371·4
−17	900·0	41	1018·4	99	1136·7	157	1255·1	215	1373·5
−16	902·0	42	1020·4	100	1138·8	158	1257·1	216	1375·5
−15	904·1	43	1022·4	101	1140·8	159	1259·2	217	1377·5
−14	906·1	44	1024·5	102	1142·9	160	1261·2	218	1379·6
−13	908·2	45	1026·5	103	1144·9	161	1263·3	219	1381·6
−12	910·2	46	1028·6	104	1147·0	162	1265·3	220	1383·7
−11	912·2	47	1030·6	105	1149·0	163	1267·3		
−10	914·3	48	1032·7	106	1151·0	164	1269·4	220	1383·7
−9	916·3	49	1034·7	107	1153·1	165	1271·4	230	1404·1
−8	918·4	50	1036·7	108	1155·1	166	1273·5	240	1424·5
−7	920·4	51	1038·8	109	1157·1	167	1275·5	250	1444·9
−6	922·5	52	1040·8	110	1159·2	168	1277·5	260	1465·3
−5	924·5	53	1042·9	111	1161·2	169	1279·6	270	1485·7
−4	926·5	54	1044·9	112	1163·3	170	1281·6	280	1506·1
−3	928·6	55	1046·9	113	1165·3	171	1283·7	290	1526·5
−2	930·6	56	1049·0	114	1167·3	172	1285·7	300	1546·9
−1	932·7	57	1051·0	115	1169·4	173	1287·8		
0	934·7	58	1053·1	116	1171·4	174	1289·8	300	1546·9
1	936·7	59	1055·1	117	1173·5	175	1291·8	400	1751·0
2	938·8	60	1057·1	118	1175·5	176	1293·9	500	1955·1
3	940·8	61	1059·2	119	1177·6	177	1295·9	600	2159·2
4	942·9	62	1061·2	120	1179·6	178	1298·0	700	2363·3
5	944·9	63	1063·3	121	1181·6	179	1300·0	800	2567·3
6	947·0	64	1065·3	122	1183·7	180	1302·0	900	2771·4
7	949·0	65	1067·3	123	1185·7	181	1304·1	1000	2975·5

375. **Increase of pressure due to increase of temperature.** — If air or gas be included within any limits which prevent its expansion by increase of temperature, its elastic force or pressure will be increased in the same proportion as its volume would be increased if it were not thus confined. Thus, if a certain quantity of air confined under a given pressure receive such an increase of temperature as would cause it to expand into double its volume, and if, after having so expanded, it be subject to such an increased pressure as will reduce it to its primitive volume, it will acquire double its primitive pressure. This follows from the principles already established, that the pressure of air and gas is universally as the volume into which they are compressed.

376. It will be convenient, however, to establish general formulæ by which the relation between the volume and temperature of the same gases under different pressures may be expressed, so that the volume at any given temperature and pressure being given, the volume at any other temperature and pressure may be obtained.

It has been already shown that at the same temperature the volume will be inversely as the pressure (213.); so that, if V and V' be two volumes at the same temperature and under the pressures P and P', we shall have

$$V : V' :: P' : P;$$

and therefore

$$V' = V \times \frac{P}{P'}.$$

Hence it follows, that if the same quantity of air or gas be simultaneously submitted to changes of temperature and pressure, the relation between its volumes, pressures, and temperatures, will be expressed by the general formula

$$\frac{V}{V'} = \frac{490 \pm T}{490 \pm T'} \times \frac{P'}{P};$$

where T and T' express the number of degrees above or below 32° at which the temperature stands, + being used when *above* and − when *below* 32°, and the pressures being expressed in the usual manner by P and P'.

By this formula, the volume of a gas at any proposed temperature and pressure may be found, if its volume at any other temperature and pressure be given.

377. **Examples.** — The expansion and contraction of air explain a multitude of phenomena which present themselves in the natural world, in domestic economy, and in the arts.

378. In the ventilation and warming of buildings, the entire process, whatever expedients may be adopted, is dependent upon this principle. When a fire is lighted in an open stove to warm a

room, the smoke and the gaseous products of combustion, ascending the chimney, soon fill the flue with a column of air so expanded by heat as to be lighter, bulk for bulk, than a similar column of atmospheric air. Such a column, therefore, will have a buoyancy proportional to its relative lightness. This upward tendency is what constitutes the draft of the chimney; and this draft will accordingly be strong and effective in just the same proportion as the column of air in the chimney is kept warm. When the fire is first lighted, the chimney being filled with cold air, there is no draft, and, consequently, the flame and smoke often issue into the room. According as the column of air in the chimney becomes gradually warm, the draft is produced and increased. The draft is sometimes stimulated by holding burning fuel for some time in the flue, so as to warm the lower strata of air in it.

But the most effectual method of stimulating the draft when the fire is lighted is by what is called a *blower*, which is a sheet of iron that stops up the space above the grate bars, and prevents any air from entering the chimney except that which passes through the fuel, and produces the combustion. This soon causes the column of air in the chimney to become heated, and a draft of considerable force is speedily produced through the fire.

379. An open chimney differs from a close stove, inasmuch as the former serves the double purpose of warming and ventilating the room, whereas the latter only warms, and can scarcely be said to ventilate. In a close stove, no air passes through the room to the flue of the chimney, except that which passes through the fuel, and that is necessarily limited in quantity by the rate of combustion maintained in the stove. In an open fire-place, on the other hand, two independent currents of air pass into the flue, one is that which passes through the fuel and maintains the combustion, and the other, which is far more considerable in quantity, is that which passes through the opening of the fire-place above the grate.

The temperature of the column in the flue is due entirely to the former, and the activity of the combustion will be determined by the relative magnitudes of the grate and the space above it; these two magnitudes representing the proportion in which the open stove serves the two purposes of warming and ventilation, the grate representing the function of warming, and the space above it the function of ventilating. Even when there is no fire lighted in the grate, the column of air in the chimney is in general at a higher temperature than the external air, and a current will therefore in such case be established up the chimney, so that the fire-place will still serve, even in the absence of fire, the purposes of ventilation. In very warm weather, however, when the external air is at a higher temperature than the air within the building, the effects are

reversed; and the air in the chimney being cooled, and therefore heavier than the external air, a downward current is established, which produces in the room the odour of soot. To prevent this, a trap or valve is usually provided in it, which can be closed at pleasure, so as to intercept the current. It should be observed, however, that this trap should only be closed when a downward current is established; since, at other times, even in the absence of fire, the ventilation of the apartment is maintained.

380. In all apparatus adapted to warm buildings, the fact that warm air is more expanded, and therefore lighter, bulk for bulk, than cool air, requires to be attended to. It is usual to admit the warm air through apertures placed in the lower parts of a room, because it will ascend by its buoyancy and mix with the colder air, whereas if it were admitted by apertures near the ceiling it would form strata in the upper part of the room, and would escape at any apertures which might be found there. But if there be means of escape only in the lower part of the room, then the strata of warm air let in above will gradually press down upon the cool air below and force it out through the chimney, doors, windows, or other apertures.

In general, the air contained in an apartment collects in strata arranged according to its temperature, the hotter air collecting near the ceiling, and the strata decreasing in temperature downwards. Thermometers placed at different heights between the floor and the ceiling would accordingly show different temperatures. The difference of these temperatures is sometimes so considerable, that flies will continue to live in one stratum which would perish in another.

If the door of an apartment be open it will be found that two currents are established through it, the lower current flowing inwards and the upper outwards. If a candle be held in the doorway near the floor, it will be found that the flame will be blown inwards; but if it be raised nearly to the top of the doorway, the flame will be blown outwards. The warm air in this case flows out at the top, while the cold air flows in at the bottom.

381. **Warming buildings by heated air.**—Although open fire-places placed in dwelling-rooms are agreeable to the eye, and healthful so far as they generally ensure an efficient ventilation, they are extremely costly, an enormous proportion of the heat developed by the fuel passing up the chimney without in any way contributing to the warmth of the room. In public buildings and other places, where all the apartments can be warmed by a common apparatus, the object is attained with much greater economy. Two methods are practised; one by currents of heated air, and the other by currents of heated water.

The method of warming buildings by currents of heated air will be easily understood by reference to *fig.* 239., where B is a

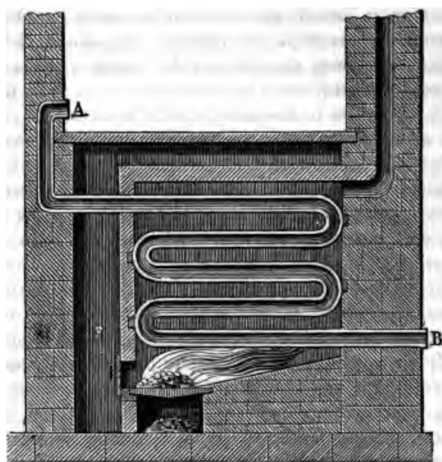


Fig. 239.

furnace constructed in the basement of the building, over which there is a metal pipe carried, following a winding course. The flame and heated air, passing round this pipe, raise the air in it to a high temperature. A current of cold air enters at the end B of the pipe which is outside the building, and after following the course of the pipe, issues at A into the apartment to be heated. Meanwhile, the smoke and heated air which has warmed the air-pipe, escapes up the chimney.

It is most important to observe that in all cases where these "*calorifères*," as they are called, are used, some efficient means of ventilation should be provided to play the part of the open fire-place.

382. **Ventilation of mines.**—Some of the methods by which this operation is effected have been already explained. We shall now notice one which depends on the production of currents of air by artificial changes of temperature. It would be easy to produce a current in a shaft by maintaining a fire in it, since in that case the shaft would, in fact, be converted into a chimney, and would ventilate the mine upon the same principle as that on which an open chimney, with a fire under it, ventilates a room. But in the case of mines, such an expedient is sometimes attended with danger, inasmuch as the gases evolved are occasionally explosive. An

expedient has, therefore, been in some cases adopted by which, while all communication between the fire and the air in the shaft is intercepted, the ventilating current is, nevertheless, established. The principle on which this depends is easily explained. If a stove pipe be observed ascending through a room, it will be easy to show that when it is strongly heated, ascending currents of air are established around it. Thus, if light be directed towards it, so as to make it project a shadow, the agitation of the ascending air around it will also produce a visible undulating shadow along the borders of the shadow of the stove pipe.

The existence of the current may be rendered still more manifest by attaching to the side of the stove pipe a wire, on which a piece of paper cut in the shape of a spiral may be suspended, as

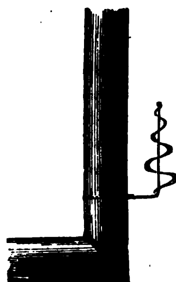


Fig. 240.

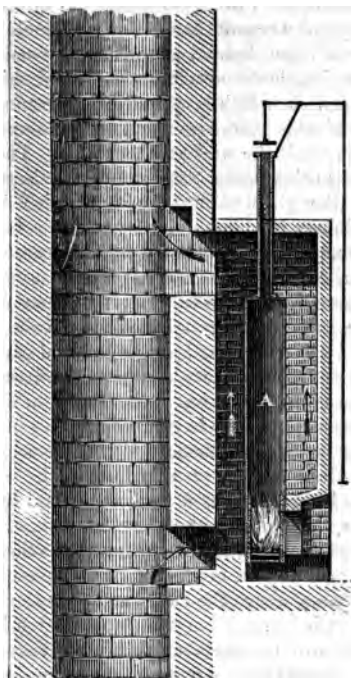


Fig. 241.

shown in *fig*. 240. The upward current will immediately put the paper in motion, and make it revolve rapidly round the wire.

Upon this principle a current is established in the shaft of a

mine by erecting a stove in a short shaft built in juxtaposition with it. Such an arrangement is shown in vertical section in *fig.* 241. The shaft of the mine is represented on the left of the figure, and the ventilating shaft communicating with it at top and bottom on the right. At the base of the ventilating shaft a stove is established, the pipe of which, A, passing up the middle of the shaft, issues from the top, where it is provided with a damper to regulate the draft. The stove is built into the base of the shaft, so that the fire has no communication with the air in it, and the pipe passes through the top of the shaft, so as to be air-tight. Upward currents are established round the pipe, A, upon the principle already explained. These currents have the effect of drawing the air through the lower, and discharging it through the upper opening, and thus establishing an upward current in the shaft.

383. **Argand lamp.** — The combustion which produces the flame of an Argand lamp is maintained upon the same principle as that by which the combustion is maintained in a common fire-place. The wick, which is cylindrical, surrounds a brass tube which communicates at its lower end with the external air. A glass chimney surrounds the wick and the flame. The air, ascending through the glass tube, passes the flame and is heated by it, and then ascends in the glass chimney within which it is confined. This glass chimney is, therefore, filled with a column of heated air, which has a buoyancy proportional to its expansion, and ascends with a proportionate force, fresh air being supplied to the wick continually through the brass tube already mentioned. But as the column of air ascending through this brass tube would only touch the flame on its external surface, the internal parts of the column would not be so strongly heated. To increase the heat imparted to the air, therefore, a metal wire is placed in the centre of the brass tube, which supports a button a little less in diameter than the wick at the level of the flame. When the column of air which ascends in the tube encounters this button, the central parts of the column are intercepted, and can only ascend by passing round the edge of the button, and therefore in contact with the flame. By this expedient all the air which ascends through the brass tube is made to pass in close contact with the flame before it can enter the glass chimney above the flame, and thus the intensity of the force of the draft is increased and the combustion is augmented.

It will be explained hereafter that flame is gas heated to such an intense degree as to become luminous. It is in consequence of its levity that it always ascends in the atmosphere.

384. **Experiments.** — The expansion of air by heat and its contraction by cold may be made manifest by a variety of simple and easily executed experiments. If a common drinking glass be

inverted and held over the flame of a lamp or candle for some time, it will be filled with air heated by the flame; if it be then suddenly plunged with its mouth downwards in water, the water will be found to rise in the glass to a height above the level of the water outside the glass. The cause of this is, that the air which fills the glass, having been previously rarefied by heat and afterwards cooled, when removed from the lamp, is contracted so as to fill a less space than the capacity of the glass which it filled when heated previous to immersion.

This experiment may be rendered still more striking by using a glass bulb blown at the end of a tube, like a thermometric tube, instead of a glass. Let such a bulb be held for some minutes over the flame of a spirit-lamp. The air which fills it will become highly expanded and rarefied by the heat. Let the open end of the tube be then plunged in water, the bulb being presented upwards. After some time, when the tube has cooled and the air within it contracted, the water will rise in the tube, and will nearly fill the bulb, the portion of the bulb not filled being the space within which the air previously heated had been contracted by cooling.

385. **Liquids.** — The liquid state is one of transition between the solid and the vaporous states. Solids by heat are converted into liquids, and liquids into vapours.

The liquid state, therefore, is maintained between two limits of temperature; a lower limit, at which the liquid would solidify, and a higher limit, at which it would vaporise. In different liquids these limits are separated by a greater or less range of temperature. In some, alcohol for example, the point of solidification stands at a very low temperature on the scale; while in others, as in some of the oils, the point of vaporisation is placed at a very high limit. In others, as in mercury, these points are widely separated, the vaporising point being at a very high, and the freezing point at a very low temperature.

386. It is found in general that the rate of dilatation of liquids is not uniform, like that of solids and gases, and that it not only increases as the temperature is elevated, but is subject to certain irregularities as it approaches the points at which the liquid would pass, on the one hand, into the solid, and, on the other, into the vaporous state.

387. Since by dilatation and contraction the proportion of the volume of the liquid to its weight is varied, all the methods which have been explained in (76.) *et seq.* for ascertaining the specific gravity of liquids will be equally applicable to determine their dilatation and contraction. If, for example, a given volume of liquid at a certain temperature weigh 1000 grains, and the same

volume at another temperature weigh only 950 grains, the proportion of the volumes which have equal weights will be the inverse of those numbers, that is, of 950 to 1000.

The only body in the liquid state whose variations of volume through a considerable range of the thermometric scale are found to be exactly proportional to its change of temperature, is mercury.

It has been ascertained that, from 13° below the freezing point to 212°, the increments of volume in this liquid for equal increments of temperature are equal.

The principal liquids whose rates of dilatation have been submitted to exact experimental investigation, are water, mercury, and alcohol. The increment of volume which each of these liquids receives from 32° to 212° is $\frac{1}{23}$rd of the volume at 32° for water, $\frac{1}{55}$th for mercury, and $\frac{1}{8}$th for alcohol.

388. Water, as it falls in temperature towards the freezing point, exhibits phenomena which form a striking exception to the general laws of dilatation and contraction by temperature. As its temperature is lowered, the rate at which it contracts is found to diminish until it arrives at the temperature of 38°·8 Fah., when all contraction ceases, and, if the temperature be further lowered, the volume is observed to remain stationary for some time; but, on lowering it still more, instead of contraction, a dilatation is produced, and this dilatation continues at an increasing rate until the water is congealed. It appears, therefore, that at the temperature of 38°·8 the density of water is a maximum. It is found that for a few degrees above and below such temperature of greatest density, the dilatation is the same; thus, at 1° above and 1° below 38°·8, and at 2° above and 2° below that point, the specific gravities are exactly equal.

389. The experiments of Blagdon and Gilpin fixed the temperature of greatest condensation at 39°; those of Lefevre, Gineau, Halstrom, Hope, and Rumford, fixed it a little above 40°. More recent experiments, however, conducted under conditions of greater accuracy by Münke and Stampfer, have determined it at 38°·8.

390. Water, at its greatest density, is taken as the base of the uniform system of measures adopted in France, the unit of weight being the weight of a cube of distilled water taken at its greatest density, the side of the cube being the length of a centimetre, or the one hundredth part of a metre, which is the linear unit. The length of the metre is 39·37 English inches.

391. It has been already proved that if liquids having different specific gravities be placed in the same vessel without mixing with each other, they will arrange themselves in strata according to

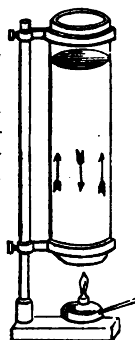
their specific gravities, the heavier being below the lighter. This principle will seem to explain several facts. If cold water be poured into a vessel, a thermometer being immersed in it, and hot water be carefully poured over it, so as to prevent the liquids being mixed, the hot water will float on the cold. The thermometer immersed in the cold water will not rise, nor will a thermometer immersed in the hot water fall. But if the water be agitated so as to mix the two strata, then their temperatures will be equalised and the lower thermometer will rise and the upper fall. If, however, hot water be first poured into the vessel, a thermometer being immersed in it, and cold water be then carefully poured over it, so as to prevent such agitation as would cause the fluids to mix, and a thermometer be also immersed in it, it will be found that the lower thermometer will rapidly fall and the higher one will rise; in fact, in this case the cold water descends through the hot water by its superior gravity, and the two fluids of different temperatures, in passing through one another, become mixed, and the whole mass takes an intermediate temperature.

392. The process by which water is boiled by heat applied to the bottom of a vessel, is explained on this principle. The water in contact with the bottom of the vessel being heated, is expanded, and becomes lighter, bulk for bulk, than the strata over it. It therefore rises, and the water above it falls, and, in its turn being expanded by heat, is made to rise. There is thus a continual current of the water heated by the fire upwards, and a counter current of the colder water forming the superior strata downwards; and this goes on until all the water in the vessel has been raised to the boiling point.

393. It is easy to show that any source of heat, however intense, applied to the upper surface of water, would be incapable of raising the temperature of the mass. Thus, if we suppose oil at the temperature of 300° poured upon the surface of water in a vessel at 50°, the oil will float upon the water, and a thin stratum of the water in contact with it will have its temperature raised, and will therefore be expanded; but, being lighter, bulk for bulk, than the colder water under it, it will still float on the top. No interchange of currents will take place, by which the heated water forming the upper stratum can be mixed with the water forming the lower stratum; and, as water is a non-conductor of heat, as will hereafter be shown, the heat of the oil, and of the stratum of water in immediate contact with it, will not be propagated downwards. It would be possible for a cake of ice to remain in the bottom of such a vessel without being melted, notwithstanding the stratum of oil at 300° floating upon its surface.

394. The system of upward and downward currents produced

by heat applied to the bottom of a vessel containing a liquid, may be rendered manifest by the following experiment. Let a tall jar (*fig.* 242.) be filled with cold water, and let some amber powder be thrown into it. The particles of this powder being equal in weight to water, bulk for bulk, or nearly so, will remain suspended, and may be seen through the sides of the vessel. Let this jar be immersed to some depth in a vessel of hot water, so that the lowest strata of the water in it may become gradually heated. The water in the bottom of the jar will now be observed continually to ascend, carrying the amber particles with it, while the colder water in the upper part will descend. The contrary currents will be rendered manifest to the eye by the particles of amber which they carry with them.


Fig. 242.

If heat be applied to the sides of the cylindrical jar, but not to the bottom, the water immediately in contact with the sides, becoming heated, will ascend. The water in the centre of the jar, on the other hand, being removed from the source of heat, will retain its temperature, and will of course sink as the water next the side rises. In this case, two distinct currents will be seen, one immediately next the surface of the jar continually ascending, and the other in the centre of the jar continually descending.

This may be shown by placing the cylindrical glass jar within another somewhat greater in diameter, and pouring a hot liquid in the space between them.

395. **Warming buildings by hot water.** — A section of one of the forms of apparatus used for this purpose is shown in *fig.* 243. A furnace, F, is established in the basement, surrounded by a boiler *o o* of sufficient capacity. From the top of this boiler a pipe A proceeds vertically upwards to the bottom of a reservoir B established at the roof of the building. This reservoir is closed at the top, but is provided with a safety valve *c*, which opens whenever the water in B produces steam which exceeds a certain pressure. From the bottom of the reservoir B, two other tubes D D descend, which communicate by branches with lateral tubes leading into all the rooms to be warmed. After passing through all these, and being carried back by return pipes, the series of descending pipes terminates at the bottom of the boiler *o o* where they enter it.

Let us now suppose that water is poured into the reservoir B until the boiler *o o*, the entire series of pipes and reservoirs *a b c d e f*, placed in all the rooms to be warmed, and the reservoir B, shall be filled. If a fire be then lighted in a furnace F, a current

of heated water will rise in the pipe A, and will be replaced by an equal quantity of cold water flowing in through the lateral pipes

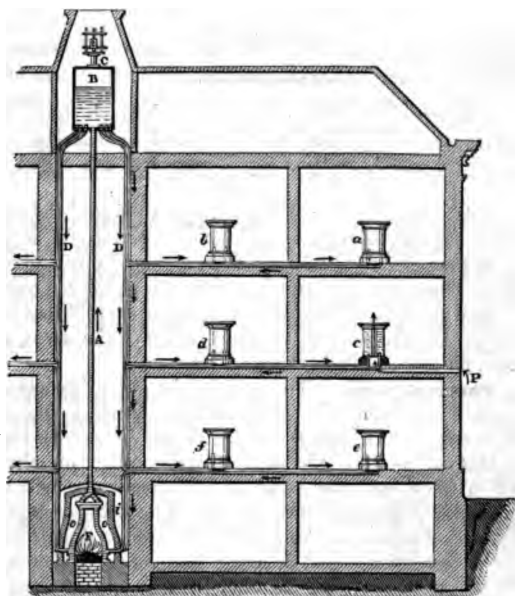


Fig. 243.

at the bottom of the boiler. In this way there will be a continual interchange of hot water sent upwards through A, and cold water flowing in through the lateral pipes, until the entire quantity of water filling the whole system of pipes and the reservoir B has attained a certain temperature.

It will attain this limit of temperature so soon as the heat radiated from the surfaces of all the pipes becomes equal to the heat developed in the furnace F.

CHAP. IV.

CALORIMETRY.

396. The department of the physics of heat devoted to the quantitative analysis of that agent is called *calorimetry*, and the instruments by which its quantity is measured are called *calorimeters*.

397. If the same quantity of heat always produced the same or equal thermometric changes, every thermometer would be a calorimeter, and *calorimetry* would not form a part of this subject distinct from *thermometry*. But not only do equal quantities of heat produce unequal thermometric changes on different bodies, but even on the same body at different points of the scale, and in some cases no thermometric change whatever.

398. **Thermal unit.** — To reduce heat to arithmetical expression, it is necessary that some suitable thermal measure be adopted, and a thermal unit selected. It may be assumed as self-evident that to produce the same thermal effect on the same quantity of the same body under like circumstances will always require the same quantity of heat. Thus it is apparent, that to raise a pound of pure water from 32° to 33°, or to liquefy a pound of ice, or to convert a pound of water into vapour under a given pressure, will always require the same quantity of heat, from whatever source such heat may proceed. Water has been selected as the standard of thermal measure, for reasons nearly the same as those which have determined its selection as the standard of specific gravity (71.) *et seq.* We shall, therefore, take as the thermal unit the quantity of heat which is necessary to raise a pound of pure water from 32° to 33°.

399. **Specific heat.** — The quantity of heat which is necessary to raise a pound of any other body from 32° to 33°, being in general different from that which would produce the same effect on water, and in general being different for different species of bodies, is called their *specific heat*, for the same reason that the weight they include under the same volume is called their specific gravity.

400. The specific heat of a body is said to be uniform throughout any extent of the thermometric scale when it requires the same quantity of heat to raise the temperature one degree through such extent of the scale. If H express the quantity of heat necessary to raise W lbs. of a body from the temperature expressed by

T′ to the temperature expressed by T, the specific heat being expressed by S and being uniform, we shall therefore have

$$H = S \times (T - T') \times W;$$

that is to say, the quantity of heat is found by multiplying together the numbers expressing the specific heat, the elevation of temperature, and the weight in lbs. When the quantity of heat necessary to raise a body one degree is different in different parts of the scale, the specific heat is said to be *variable*; and when it does so vary, it is in general found to increase with the temperature.

401. **Calorimetric problems.** — Three methods have been practised for the solution of calorimetric problems: 1st, by measuring the heat by the quantity of ice it liquefies; 2ndly, by calculating it by means of mixing or bringing into close juxtaposition bodies at different temperatures so that their temperatures shall be equalised; and 3rdly, by observing the rate at which heated bodies cool.

402. The calorimeter of Lavoisier and Laplace is based upon the first of these principles.

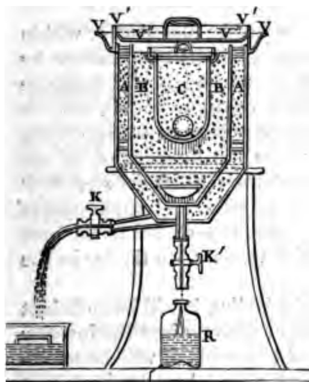


Fig. 244.



Fig. 245.

This apparatus is represented in *fig.* 244. in section, and in *fig.* 245. in perspective. Two similar metallic vessels V and V′, are constructed, one a little smaller than the other, so that, when applied one within the other, a small space A may be left between them. From the bottom of the external vessel V a discharge pipe, with

a stop-cock K, proceeds. From the bottom of the inner vessel a similar pipe proceeds, which passes water-tight through the bottom of the vessel V, and is also furnished with a stop-cock K′.

This pipe K′ is inserted into a close vessel R. The external vessel V has a close cover, by which all communication with the external air is cut off, and the inner vessel V′ is likewise furnished with a small cover, by which all communication with the space A is intercepted. The space A between the two vessels is filled with pounded ice; and if the apparatus be placed in an atmosphere above 32°, this ice will be gradually liquefied, and the water produced by it will flow off through the cock K, when the stop-cock is open, and will be received in the vessel B. The space A being kept continually supplied with ice, it is evident that the interior vessel V′ will be maintained constantly at the temperature of 32°, and the air included in it, and any objects placed in it will be necessarily reduced to that temperature.

A third vessel V″ is now placed within the second V′, and the space B between the second and third is filled with pounded ice, in the same manner as the vessel A. But it is evident that this ice cannot be affected by the temperature of the external air, since it is surrounded with the melting ice included in the space A, which is continually at 32°.

If any object at a temperature above 32° be placed at C, within the vessel V″, this object will gradually fall in its temperature by imparting its heat to the ice in the space B; and it will continue to impart heat, and its temperature will continue to fall, until it arrives at the temperature of 32°, when it will cease to liquefy the ice round it. The water proceeding from the liquefaction of the ice in the space B, is discharged through the pipe K′, the stop-cock being opened, and is received in the vessel R. The quantity of water thus received in R will therefore be proportional to the heat imparted by the body contained in the vessel V″ to the ice in the space B.

If this apparatus be applied to solid bodies, it will be sufficient to introduce the body under experiment directly into the interior of the vessel V″; but if it be applied to liquids, it will be necessary that the liquid under experiment should be contained in a vessel, which vessel is introduced into V″. In this case, the vessel containing the liquid should be reduced to the temperature of 32° before receiving the liquid, or, if not, the vessel should be raised to the temperature of the liquid, and introduced empty into the calorimeter, so as to ascertain the quantity of ice it would dissolve empty in falling from the temperature of the liquid to 32°. When the vessel is introduced, filled with the liquid, the quantity of ice

liquefied will be the sum of the quantities liquefied by the vessel and by the liquid which it contains. But the quantity liquefied by the vessel being previously ascertained and subtracted, the remainder will be the quantity dissolved by the liquid contained in the vessel.

403. If equal weights of the same body, placed in the apparatus at different temperatures, cause quantities of water to be deposited in B which are proportional to the temperatures through which they fall, it will follow that within such limits the specific heat is uniform. And, if the quantity of water deposited in B be divided by the number of degrees through which the temperature of the body placed in the calorimeter has fallen, the quantity of ice dissolved by the heat corresponding to one degree will be found. This, in fine, being divided by the weight of the body placed in the calorimeter expressed in pounds, the weight of ice dissolved by the heat which would raise 1 lb. of the body one degree will be determined.

To express this in arithmetical symbols: —

Let W = the weight of the body placed in the calorimeter,
T = its temperature,
W′ = the weight of water deposited in B while the body is reduced from T° to 32°,
x = weight of ice dissolved by the heat which would raise 1 lb. of the body one degree.

We shall then have

$\frac{W'}{(T-32)}$ = the weight of ice dissolved by the heat which would raise W one degree;

and therefore,

$$x = \frac{W'}{W \times (T-32)}.$$

404. **Specific heat of water.** — In applying this method of experimenting to water, it is found that between the freezing and boiling points its specific heat is sensibly uniform, and that the heat necessary to raise 1 lb. of water one degree is that which would dissolve the 142·65th part of a lb. of ice, so that in the case of water we have $x = \frac{1}{142 \cdot 65}$.

405. **Other bodies.** — Let the specific heat of the body W be expressed by S, that of water being the unit. Hence we shall have,

$$S : 1 :: \frac{W'}{W \times (T-32)} : \frac{1}{142{\cdot}65};$$

and consequently,

$$S = \frac{142{\cdot}65 \times W'}{W \times (T-32)};$$

which gives the following

RULE.

Multiply the weight of ice dissolved by 142·65, *and multiply the weight of the body which dissolves the ice by the number of degrees of temperature it loses, and divide the former product by the latter. The quotient will be the specific heat of the body.*

406. When two bodies at different temperatures are mixed, or brought into juxtaposition in such a manner that that which has the higher temperature may transfer to that which has the lower temperature, such a portion of its heat that the temperatures may be equalised, the relation between the specific heats may be determined, provided no chemical action nor any change of state be produced by the contact or mixture.

Let the weights of the two bodies be W and W', their temperatures T and T', and their specific heats S and S'; and let t be their common temperature, after the thermometric equilibrium has been established. It will therefore follow that the temperature lost by W will be $T-t$, and the temperature gained by W' will be $t-T'$. But from what has been already explained, the quantity of heat lost by W will be expressed by $S \times W \times (T-t)$, and the quantity of heat gained by W' will be expressed by $S' \times W' \times (t-T')$. But since the quantity of heat lost by W is imparted to W', these two quantities must be equal, and consequently we must have

$$W \times S \times (T-t) = W' \times S' \times (t-T');$$

and from this we infer that

$$S : S' :: W' \times (t-T') : W \times (T-t);$$

that is to say, the specific heats of the two bodies are in the inverse proportion of the products of their weights, and the temperatures which they gain and lose.

This method of determining the relation between the specific heats is applicable either to two liquids, or to a solid and a liquid, provided that when they are mixed or brought together, no chemical action takes place between them, and provided the solid be not

liquefied. But if such action ensue, it is generally attended with the development or absorption of sensible heat, by which the common temperature would be rendered either higher or lower than that which would result from mere admixture.

If one of the bodies W′ be water, we shall have S′=1, and therefore

$$S=\frac{W'\times(t-T')}{W\times(T-t)};$$

from which follows the

RULE.

Let the weight of a heated body immersed in water be multiplied by the temperature it loses, and let the weight of the water be multiplied by the temperature it gains. The quotient obtained by dividing the latter product by the former will be the specific heat of the body.

The method of determining the specific heat of gaseous bodies by means of the water calorimeter of Count Rumford, is similar in principle to the preceding method. This apparatus consists of a worm carried through a vessel of water in a manner similar to the worm of a still. The gas, being previously weighed, prepared, and dried, is raised to 212° by passing it through a similar worm placed in a vessel of boiling water. It is then passed through the worm of the calorimeter and raises the temperature of the water, its own temperature falling. The elevation of the temperature of the water, and the fall of the temperature of the gas being observed, data are obtained from which the specific heat of the gas is calculated.

407. Equal and similar volumes of two bodies raised to the same temperature and allowed to cool under precisely similar circumstances, are assumed to lose equal quantities of heat per minute. In order to ensure the exact fulfilment of these conditions, a multitude of precautions are necessary which cannot be detailed here. The result, however, is, that by observing the intervals of time which are necessary for equal volumes of the two bodies to fall one degree, we obtain the ratio of the quantities of heat which they lose, and this being determined for equal volumes, the quantities for equal weights may be inferred from the specific gravities of the bodies, and the specific heats will thus be obtained.

This was applied with considerable success by Dulong and Petit, and also by Regnault.

408. Having thus explained the principal methods by which the specific heat of bodies has been experimentally ascertained, we

shall now state the most important results which have been attained in this department of the physics of heat.

409. The specific heat of bodies diminishes as their density is increased, and *vice versâ*. This explains the fact that mechanical compression will, without any addition of heat, raise the temperature. If metal be hammered it becomes hot, and it is even affirmed that iron has been rendered incandescent in this manner.

410. **The fire-syringe.** — The syringe in which compressed air is made to inflame amadou acts on this principle. The air compressed under the syringe acquires a greatly diminished specific heat, and, consequently, although it has received no heat from any external source, the same heat which before compression only gave it the common temperature of the surrounding medium, gives it, after compression, a temperature high enough to produce the ignition of a highly inflammable substance like amadou.

411. **Specific heat of gases and vapours.** — In general, no practicable force can prevent the dilatation of solids and liquids when their temperature is elevated. This, however, is not the case with gases and vapours, which, when heat is imparted to them, may either be permitted to expand under a given pressure, like solids and liquids; or may be confined to a given volume, which they will continue to fill in consequence of their elasticity (211.), however their temperature may be lowered, and which they will not exceed, however their temperature may be raised. In this case, the heat imparted or abstracted is manifested by a corresponding change of pressure of the gas or vapour instead of dilatation or contraction.

412. **Specific heat under constant pressure and constant volume.** — By the specific heat of a gas or vapour is to be understood its specific heat when subject to a constant pressure; that is to say, when it is susceptible, like solids and liquids, of dilatation and contraction. Specific heat is, however, a term sometimes, though not so properly, applied to the heat necessary to raise the gas or vapour one degree when confined within a given volume. This last is sometimes also called, for distinction, the *relative heat*.

413. The specific heat of a gas or vapour under a given pressure is greater than under a given volume. This difference is explained by the fact that, in expanding, the temperature falls, and therefore that, when confined to a given volume, less heat is sufficient to produce a given elevation of temperature than when confined under a given pressure, where the dilatation diminishing the density absorbs a portion of the heat. For atmospheric air, oxygen and hydrogen, the ratio of the specific heat under a given pressure is to the specific heat in a given volume as 1·421 to 1. For car-

bonic acid it is 1·338; for carbonic oxide, 1·428; for nitrous oxide, 1·343; and for olefiant gas, 1·240.

414. The expansion of high-pressure steam escaping from the safety valve forms a remarkable instance that the same quantities of heat may give very different temperatures to a body, in different states of density. Steam produced under a pressure of 35 atmospheres has the temperature of 419°. When such steam escapes into the atmosphere, it undergoes a prodigious expansion without losing heat, and suffers a considerable fall in temperature.

415. **Low temperature of superior strata of atmosphere.**— The circumstance that rarefied air has an increased capacity for heat, will explain the very low temperatures which are known to exist in the higher regions of the atmosphere.

This effect becomes extremely sensible when we ascend to any considerable height, as has been manifest in ascending high mountains and in balloons. Upon these occasions, the cold has sometimes become so intense, that mercury in the thermometer has been frozen. In strata so elevated that the permanent temperature of the air is below 32°, water cannot continue in the liquid state; it exists there only in the form of ice or snow, and we accordingly find eternal snow deposited upon those parts of high mountains which exceed this limit of temperature.

416. **Line of perpetual snow.** — The level of that stratum of air which by its rarefaction reduces the temperature to 32°, is called the *line of perpetual snow*, and its position in different parts of the earth varies, the height increasing generally in approaching the equator, and falling towards the poles. The various conditions which affect the position of this line in different parts of the earth will be explained in a subsequent Book.

417. **Liquefaction of gases.** — The elevation of temperature produced by the compression of gases has supplied means of reducing some of them to the liquid form. Gases may be considered as vapours raised from liquids, which have received, after their separation from the liquid which produced them, a large additional supply of heat. It is to the effects of this surplus heat that their permanent maintenance in the gaseous state must be ascribed. If, by any means, they can be deprived of this surplus heat, so that no heat shall be left in them except that which they received in the process of vaporisation, any further loss of heat would necessarily cause them to return, in more or less quantity, to the liquid form. But if the specific heat be so great, that, notwithstanding all the heat transmitted to the gas after taking the vaporous form, it still has attained only the common temperature of the atmosphere, it is clear that it can only be restored to the liquid form, either by reducing its temperature to an immense extent, by the applica-

tion of freezing mixtures, or by first raising its temperature by high degrees of mechanical compression, and then allowing it to fall to the temperature of surrounding objects, or, in fine, by combining both these methods. Thus atmospheric air, at the common temperature of 50°, being compressed into a diminished volume, in the proportion of 10000 to 3, its temperature would be raised through an extent of 13500° of heat, according to Leslie's experiment. This heat being immediately abstracted by the surrounding objects, its temperature would fall to that of the medium in which it is placed. Thus, without the application of a freezing mixture, or other means of cooling, an immense abstraction of heat may be effected; and this may be continued so long as a mechanical force adequate to the further compression of the gas could be exerted. Freezing mixtures may then be applied to the further reduction of temperature. Methods of producing the liquefaction of certain gases will be explained hereafter.

418. When different liquids are mixed, or when solids are dissolved in liquids, chemical phenomena are generally developed, in consequence of which the specific heat of the mixture differs from that which it would have if the constituents were merely interfused without any change in their thermal qualities. Like the other qualities of the constituents, their specific heats are in this case modified; and the compound is generally found to have a less specific heat than that which would be inferred from the specific heats of its components. When the chemical combination is thus, as it is almost universally, attended by a diminution in the specific heat of the compound as compared with that which would be computed from the specific heats of its components, it is also found that the volume of the mixture is less than the sum of the volumes of its compounds, and that the temperature of the mixture is higher than the common temperature of the liquids mixed.

Thus, for example, if a pint of water and a pint of sulphuric acid, both of the temperature of 57°, be mixed, the mixture will rise to the temperature of 212°, and the volume of the mixture will be considerably less than a quart. The chemical attraction of the particles, therefore, in this and like cases, produces condensation, and, in fact, the same effect ensues as would be produced by compression. The elevation of temperature may be explained in exactly the same manner as when bodies are compressed by mechanical force. The specific heat of the mixture being less than that which is due to its component parts, and the absolute quantity of heat contained in it not being diminished, that quantity will raise it to a much higher temperature than that which it would have had, if the specific heats remained unaltered.

419. Under equal pressures the simple gases have the same

specific heat. This uniformity, however, does not prevail among the compound gases, as will appear by the tables of specific heat of the gases.

420. **Formula for the variation of specific heat consequent on change of pressure.** — The law according to which the same gas varies its specific heat with the change of pressure or density is, according to Poisson, expressed by the formula—

$$s = s' \times \left(\frac{30}{p}\right)^{1-\frac{1}{k}}$$

where P expresses the pressure in inches of mercury. s′ the specific heat under the mean pressure of 30 inches, and the constant number, which expresses the ratio of the specific heat under a given pressure to the specific heat under a given volume, which, in the case of common air and the simple gases, is 1·421, as has been already explained, and as will appear by the tables.

421. **Relation between specific heat and atomic weight.** — On comparing together the numbers expressing the pecific heat of the simple bodies, with those which express their atomic weights or chemical equivalents, Dulong and Petit observed that the one increased in almost the exact proportion in which the other diminished, so that by multiplying them together, a product very nearly constant was obtained.

From this it would follow, upon the atomic hypothesis, that the specific heats of the atoms of all the simple bodies are equal. For in equal weights, the number of constituent atoms will be great in proportion as the individual weights of these atoms are small. The number of atoms, therefore, in equal weights, being inversely proportional to the weights of the atoms, and the specific heats being also inversely proportional to the weights of the atoms, it follows that the specific heats of equal weights are in the proportion of the number of atoms contained in those weights, and that, consequently, the specific heats of the component atoms must be equal.

This, therefore, is a quality in which the atoms of all simple bodies, however they may differ in other respects, agree, — that their temperatures are equally affected by the same quantity of heat.

That this law is not rigorously exact, however, is proved by the fact that the specific heat of the same body is different at different temperatures and in different states.

It has resulted from the researches of Regnault, that the relation between the specific heats and atomic weights, observed by Dulong and Petit in the simple bodies, also prevails among compound bodies ; and that, in general, in all compound bodies of the

same atomic composition and having similar chemical constituents, the specific heat is in the inverse ratio of the atomic weight; this law, however, being subject to the same qualification which has been already mentioned for the simple bodies.

The numerical results which manifest the prevalence of this law will be seen in the tables of specific heat.

422. **Tables of specific heat.** — The following series of tables supply, in a summary form, the results of the most recent experimental researches respecting the specific heat of bodies, and the relation between these, and their chemical constitution.

Table of specific Heats of simple and compound Bodies determined by M. Regnault.

Names of Substances.	Specific Heat.	Atomic Weights. (Oxygen = 100).	Products.
Preliminary Results.			
Brass	0·09391		
Glass	0·19768		
Water	1·0080		
Turpentine, spirit of	0·42593		
Simple bodies, pure.			
Iron	0·11379	339·21	38·597
Zinc	0·09555	403·23	38·526
Copper	0·09515	395·70	37·849
Cadmium	0·05669	696·77	39·502
Silver	0·05701	675·80	38·527
Arsenic	0·08140	470·04	38·261
Lead	0·03140	1294·50	40·647
Bismuth	0·03084	1330·37	45·034
Antimony	0·05077	806·45	40·944
Tin, Indian	0·05623	735·29	41·345
Nickel	0·10863	369·68	40·160
Cobalt	0·10696	368·99	39·468
Platinum, rolled	0·03243	1233·50	39·993
Palladium	0·05927	665·90	39·468
Gold	0·03244	1243·01	40·328
Sulphur	0·20259	201·17	40·754
Selenium	0·0837	494·58	41·403
Tellurium	0·05155	801·76	41·549
Iodine	0·05412	789·75	42·703
Mercury	0·03332	1265·82	42·149
Simple bodies, less pure.			
Uranium	0·06190	677·84	41·960
Tungsten	0·03636	1183·00	43·002
Molybdenum	0·07218	598·52	43·163
Nickel, carburetted	0·11192	369·68	41·376
Nickel, more carburetted	0·11631	369·68	42·999
Cobalt, carburetted	0·11714	368·99	43·217
Steel (Hausmann)	0·11848	339·21	40·172
„ pure metal	0·12728	339·21	
Cast iron (white)	0·12983	339·21	44·038
Carbon	0·24111	152·88	36·873
Phosphorus	0·1887	196·14	37·024
Iridium (impure)	0·03683	1233·50	45·428
Manganese, very much carburetted	0·14411	345·89	49·848
Metallic alloys.			
1 Lead, 1 tin	0·04073	1014·9	41·34
1 „ 2 „	0·04506	921·7	41·53

Names of Substances.	Specific Heat.	Atomic Weights. (Oxygen = 100.)	Products.
1 Lead, 1 antimony	0·03880	1050·5	40·76
1 Bismuth, 1 tin	0·04000	1032·8	41·31
1 „ 2 „	0·04504	933·7	42·05
1 „ 2 „ 1 antimony	0·04621	901·8	41·67
1 Bismuth, 2 tin, 1 antimony, 2 zinc	0·05657	735·6	41·61
1 Lead, 2 tin, 1 bismuth	0·04476	1023·9	45·83
1 „ 2 „ 2 „	0·06082	1088·2	66·00
1 Mercury, 1 tin	0·07294	1000·5	72·97
1 „ 2 „	0·06591	912·1	60·12
1 „ 1 lead	0·03827	1280·1	48·90
Oxides, RO.			
Protoxide of lead in powder	0·05118	1394·5	71·34
Protoxide of lead, cast	0·05089	1394·5	70·94
Oxide of mercury	0·05179	1365·8	70·74
Protoxide of manganese	0·15701	445·9	70·01
Oxide of copper	0·14201	495·7	70·39
„ of nickel	0·16234	469·6	76·21
„ of nickel, calcined at the forge	0·15885	469·6	74·60
Mean	- -	- -	72·03
Magnesia	0·24394	258·4	63·03
Oxide of zinc	0·12480	503·2	62·77
Oxides, $R^2 O^3$.			
Peroxide of iron (iron oligist)	0·16695	978·4	163·35
Peroxide of iron, slightly calcined	0·17569	978·4	171·90
Peroxide of iron, doubly calcined	0·17167	978·4	168·00
Peroxide of iron, strongly calcined			
Peroxide of iron, strongly calcined twice	0·16814	978·4	164·44
Acid, arsenious	0·12786	1240·1	158·56
Oxide of chromium	0·17960	1003·6	180·01
„ of bismuth	0·06053	2960·7	179·22
„ of antimony	0·09009	1912·9	172·34
Mean	- -	- -	169·73
Alumina (Corindon)	0·19762	642·4	126·87
„ (sapphire)	0·21732	642·4	139·61

Names of Substances.	Specific Heats.	Atomic Weights. (Oxygen =100.)	Products.
Oxides, RO^2.			
‑cid, stannic - -	0·09326	935·3	87·23
" titanic (artificial)	0·17164	503·7	86·45
" " (rutile) -	0·17032	503·7	85·79
Mean -	- -	- -	86·49
" antimonious -	0·09535	1006·5	95·92
Oxides, RO^3			
‑cid, tungstic - -	0·07983	1483·2	118·38
" molybdic - -	0·13240	898·5	118·96
" silicic - -	0·19132	577·5	110·48
" boracic - -	0·23743	436·0	103·52
Oxides.			
‑xides of magnetic iron	0·16780	1417·6	237·87
Sulphurets, RS.			
‑roto-sulphuret of iron	0·13570	540·4	73·33
‑ulphuret of nickel -	0·12813	570·8	73·15
‑ulphuret of cobalt -	0·12512	570·0	71·34
" of zinc -	0·12303	604·4	74·35
" of lead -	0·05086	1495·6	76·00
" of mercury -	0·05117	1467·0	75·06
‑roto-sulphuret of tin	0·08365	936·5	78·34
Mean - -	- -	- -	74·51
Sulphurets, R^2S^3.			
‑ulphuret of antimony	0·08403	2216·4	186·21
" of bismuth -	0·06002	3264·2	195·90
Mean - -	- -	- -	191·06
Sulphurets, RS^2.			
‑i-sulphuret of iron -	0·13009	741·6	96·45
" of tin -	0·11932	1137·7	135·66
‑ulphuret of molybdenum - - - -	0·12334	1001·0	123·46
Mean - -	- -	- -	129·56
Sulphurets, R^2S.			
‑ulphuret of copper -	0·12118	992·0	120·21
" of silver -	0·07460	1553·0	115·86
Sulphurets.			
‑yrites, magnetic -	0·16023		
Chlorates, R^2Cl^2.			
‑hlorate of sodium -	0·21401	733·5	156·97
" of potassium -	0·17295	932·5	161·19
" of mercury -	0·05205	2974·2	154·80
" of copper -	0·13827	1234·0	156·83
" of silver -	0·09109	1794·2	163·42
Mean - -	- -	- -	158·64
Chlorates, RCl^2.			
‑hlorate of barium -	0·08957	1299·5	116·44
" of strontium -	0·11990	989·9	118·70
" of calcium -	0·16420	698·6	114·72
" of magnesium	0·19460	601·0	118·54
" of lead - -	0·06641	1737·1	115·35
‑ro-chlorate of mercury	0·06889	1708·4	117·68
" of zinc -	0·13618	845·8	115·21
" of tin -	0·10161	1177·9	119·59
Mean - -	- -	- -	117·03
‑hlorate of manganese	0·14255	788·5	112·51

Names of Substances.	Specific Heats.	Atomic Weights. (Oxygen =100.)	Products.
Chlorides volatile, RCl^4			
Chloride of tin - -	0·14759	1620·5	239·18
" of titanium -	0·19145	1188·9	237·63
Mean - -	- -	- -	233·40
Chlorides volatile, R^2Cl^6.			
Chlorate of arsenic -	0·17604	2267·8	399·26
" of phosphorus	0·20922	1720·1	359·86
Mean - -	- -	- -	379·51
Bromates, R^2Br^2.			
Bromate of potassium -	0·11322	1468·2	166·21
" of silver -	0·07391	2330·0	173·31
Mean - -	- -	- -	169·76
Bromate of sodium -	0·13842	1269·2	175·63
Bromates, RBr^2.			
Bromate of lead - -	0·05326	2272·8	121·00
Iodates, R^2I^2.			
Iodate of potassium -	0·08191	2068·2	169·38
" of sodium - -	0·08684	1869·2	162·30
Prot-iodate of mercury	0·03949	4109·3	162·34
" of silver -	0·06159	2929·9	180·45
" of copper -	0·06869	2369·7	162·81
Mean- -	- .	- -	167·45
Iodates, RI^2.			
Iodate of lead - -	0·04267	2872·8	122·54
" of mercury -	0·04197	2844·1	119·36
Mean - -	- -	- -	120·95
Fluorates, RFl^2.			
Fluorate of calcium -	0·21492	489·8	105·31
Nitrates, $Az^2O^5+R^2O$.			
Nitrate of potash -	0·23875	1266·9	302·49
" of soda - -	0·27821	1067·9	297·13
" of silver - -	0·14352	2128·6	305·54
Mean - -	- -	- -	301·72
Nitrates, Az^2O^5+RO.			
Nitrate of barytes -	0·15228	1633·9	248·83
Chlorates, $Cl^2O^5+R^2O$.			
Chlorate of potash -	0·20956	1532·4	321·04
Phosphates, $P^2O^5+2R^2O$ (*Pyrophosphates*).			
Phosphate of potash -	0·19102	2072·1	395·70
" of soda -	0·22833	1674·1	382·22
Mean - -	- -	- -	389·01
Phosphate, P^2O^5+2RO.			
Phosphate of lead -	0·08208	3681·3	302·14
Phosphate, P^2O^5+RO.			
Phosphate of lime -	0·19923	1248·3	248·64
Phosphate, P^2O^5+3RO.			
Phosphate of lead -	0·07982	4985·8	397·96

Name of Substances.	Specific Heats.	Atomic Weights. (Oxygen = 100.)	Products.
Arsenites, $As^2O^5+R^2O$.			
Arsenite of potash -	0·15631	„	„
Arsenites of lead, $As^2O^5+3\,PbO$.			
Arsenite of lead - -	0·07280	5623·5	409·37
Sulphates, SO^3+R^2O.			
Sulphate of potash -	0·19010	1091·1	207·40
„ of soda - -	0·23115	892·1	206·21
Mean - - -	- -	- -	206·80
Sulphates, SO^3+RO.			
Sulphate of barytes -	0·11285	1458·1	164·54
„ of strontium -	0·14279	1148·5	164·01
„ of lead - -	0·08723	1895·7	165·39
„ of lime -	0·19656	857·2	168·49
„ of magnesia -	0·22159	759·5	168·30
Mean - - -	- -	- -	166·15
Chromates.			
Chromate of potash -	0·18505	1241·7	229·83
Bi-chromate of potash -	0·18937	1893·5	358·67
Borates, $B^2O^6+R^2O$.			
Borate of potash - -	0·21975	1461·9	321·27
„ of soda - -	0·23823	1262·9	300·88
Mean - - -	- -	- -	311·07
Borates, B^2O^6+RO.			
Borate of lead - -	0·11409	2266·5	258·60
Borates, $B^2O^6+2\,R^2O$			
Borate of potash - -	0·20478	1025·9	219·52
„ of soda - -	0·25709	826·9	212·60
Mean - - -	- -	- -	216·06
Borates, $BO^6+2\,RO$.			
Borate of lead - -	0·09046	1830·5	165·54
Tungstates.			
Wolfram - - -	0·09780	„	„
Silicates.			
Zirconia - - -	0·14558	„	„
Carbonates, CO^2+R^2O			
Carbonate of potash -	0·21623	865·0	187·04
„ of soda -	0·27275	666·0	181·65
Mean - - -	- -	- -	184·35
Carbonates, CO^2+RO.			
Carbonate of lime (Iceland spar) - - -	0·20858	631·0	131·61
Carbonate of lime (Arragonite - - -	0·20850	631·0	131·56
Marble, white - -	0·21585	631·0	136·20
„ grey - -	0·20989	631·0	132·45
Chalk, white - -	0·21585	631·0	135·57
Carbonate of barytes -	0·11038	1231·9	135·99
„ of strontium	0·14483	922·3	133·58
„ of iron- -	0·19345	714·2	138·16
Mean - - -	- -	- -	134·40
Carbonate of lead -	0·08596	1669·5	143·55
Dolomite - - -	0·21743	582·2	126·59

Specific Heats of different Bodies determined by M. Regnault.

Names.	Specific Heats.	Densities.
Animal black - - - - -	0·26085	
Charcoal - - - - -	0·24150	
Coke of cannel coal - -	0·20307	
„ of small coal - - -	0·20085	
Welsh anthracite coal - -	0·20171	
Philadelphian „ - -	0·20100	
Graphite, natural - - -	0·20187	
„ of smelting furnaces -	0·19702	
„ of gas retorts - -	0·20360	
Diamond - - - - -	0·14687	
Turpentine - - - -	0·4672	
Térébène - - - - -	0·4656	
Térébilène - - - -	0·4580	
Camphilène - - - -	0·4518	
Lemon juice - - - -	0·4879	
Orange juice - - - -	0·4886	
Gin - - - - - -	0·4770	
Petroleum - - - -	0·4684	
Steel, soft - - - - - -	0·1165	7·8609
„ tempered - - -	0·1175	7·7982
Metal of acute cymbals - -	0·0858	8·5797
„ of soft cymbals, tempered	0·0862	8·6343
Dutch tears, hard - - -	0·1923	
„ annealed - -	0·1937	
Sulphur naturally crystallised -	0·1776	
„ melted for two years -	0·1764	
„ „ for two months	0·1803	
„ „ recently -	0·1844	
Water - - - - -		
Spirit of turpentine - - -	0·4160	
Solution of chlorate of calcium	0·6448	
Spirit of wine, common at 97° -	0·6588	
„ of higher degree	0·8413	
„ of still higher -	0·9402	
Acetic acid concentrated, not crystallised - - - -	0·6501	

Specific Heats determined by M. Regnault.

Names of Bodies.	Specific Heats.			Names of Bodies.	Specific Heats.		
	From 68° to 59°.	From 59° to 50°.	From 50° to 41°.		From 68° to 59°.	From 59° to 50°.	From 50° to 41°.
stilled water - - -	,,	,,	,,	Chlorate of silicium - -	0·1904	0·1924	0·1914
rit of turpentine - -	,,	,,	,,	Chlorate of titanium - -	0·1828	0·1802	0·1810
ution of chlorate of cal-				Chloride of tin - - -	0·1416	0·1402	0·1421
ium - - - - -	0·6462	0·6389	0·6423	Protochlorate of phosphorus -	0·1991	0·1987	0·2017
rit of wine, common, No. 1.	0·6725	0·6651	0·6588	Sulphate of carbon - -	0·2206	0·2183	0·2179
,, weaker, No. 2. -	0·8518	0·8429	0·8523	Ether - - - - -	0·5157	0·5158	0·5207
,, still weaker, No. 3.	0·9752	0·9682	0·9770	,, sulphydric - - -	0·4772	0·4653	0·4715
,, common - -	0·6774	0·6540	0·6465	,, iodhydric - - -	0·1584	0·1584	0·1587
etic acid - - - -	0·6589	0·6577	0·6609	Spirit of wine - - -	0·6148	0·6017	0·5987
rcury - - - -	0·0290	0·0283	0·0281	Ether, oxalic - - -	0·4554	0·4521	0·4629
étène - - - -	0·4267	0·4156	0·4154	Spirit of wood - - -	0·6009	0·5868	0·5901
non juice - - - -	0·4501	0·4424	0·4489	Ether, iodhydric - - -	0·1569	0·1556	0·1574
roleum - - - -	0·4342	0·4325	0·4321	,, bromhydric - -	0·2153	0·2135	0·2164
zine - - - -	0·3932	0·3865	0·3999	Chlorate of sulphur - -	0·2038	0·2024	0·2048
robenzine - - -	0·3499	0·3478	0·3524	Acetic acid, crystallisable -	0·4618	0·4599	0·4587

CHAP. V.

LIQUEFACTION AND SOLIDIFICATION.

423. **Thermal phenomena attending liquefaction.**—It has been already explained, that when heat is imparted in sufficient quantity to a solid body, such body will at a certain point pass into the liquid state; and when it is abstracted in sufficient quantity from a liquid, the liquid at a certain point will pass into the solid state.

424. Certain thermal phenomena of great interest and importance are developed in the progress of these changes, which it will now be necessary to explain.

Let us suppose that a mass of ice or snow, at the temperature of 20°, is placed in a vessel and immersed in a bath of quicksilver, under which spirit-lamps are placed. Let one thermometer be immersed in the ice or snow, and another in the mercury. Let the number and force of the lamps be so regulated that the thermometer in the mercury shall indicate the uniform temperature of 200°. The mercury imparting heat to the vessel containing the ice will first cause the ice to rise from 20° to 32°, which will be indicated by the thermometer immersed in the ice; but when that thermometer has risen to 32° it will become stationary, and the ice will begin to be liquefied. This process of liquefaction will

continue for a considerable time, during which the thermometer will continue to stand at 32°; at the moment that the last portion of ice is liquefied it will again begin to rise. The coincidence of this elevation with the completion of the liquefaction may be easily observed, because ice, being lighter, bulk for bulk, than water, will float on the surface, and so long as a particle of it remains unmelted it will be visible.

Now it is evident that, during this process, the mercury maintained at 200° constantly imparts heat to the ice; yet, from the moment the liquefaction begins until it is completed, no increase of temperature is exhibited by the thermometer immersed in the ice. If during this process no heat were received by the ice from the mercury, the lamps would cause the temperature of the mercury to rise above 200°, which may be easily proved by withdrawing the vessel of ice from the mercurial bath during the process of liquefaction. The moment it is withdrawn, the thermometer immersed in the mercury, instead of remaining fixed at 200°, would immediately begin to rise, although the action of the lamps remained the same as before: from which it is obvious that the heat, which on the removal of the ice causes the mercury to rise above 200°, was before imparted to the melting ice.

425. It appears, therefore, that the heat which is received by the melting ice during the process of liquefaction is latent in it, being incapable of affecting the thermometer or the senses.

If the hand be plunged in the ice at the moment it begins to melt and at the moment that its liquefaction is completed, the sense of cold will be precisely the same, notwithstanding the large quantity of heat which must have been imparted to the ice during the process of liquefaction.

426. **Heat latent in liquefaction.** — The quantity of heat which is absorbed and rendered latent in the process of liquefaction can be directly ascertained by the calorimeter of Laplace and Lavoisier (422). To ascertain this in the case of ice, it is only necessary to place a pound of water at any known temperature in the apparatus, and observe the weight of ice it will dissolve in falling to any other temperature. In this way it will be found that in falling through 142°·65 it will dissolve a pound of ice; and in general, any proposed weight of water, in falling through this range of temperature, will give out as much heat as will dissolve its own weight of ice.

427. Hence it is inferred that, when ice is liquefied, it absorbs and renders latent as much heat as would be sufficient to raise its own weight of water from 32° to 32°+142°·65=174°·65.

428. The latent heat of water has for the last half century been estimated at 135°, that having been the result of the experimental

researches of Lavoisier and Laplace. Dr. Black's estimate was 140°, and that of Cavendish 150°. A series of experiments have lately been made, under conditions of greater precision, by MM. de la Provostaye and Desains, from which the above estimate has been inferred.

Dr. Black, who first noticed this remarkable fact, inferred that ice is converted into water by communicating to it a certain *dose* of heat, which enters into combination with it in a manner analogous to that which takes place when bodies combine chemically. The heat thus combined with the ice losing its property of affecting the senses or the thermometer, the phenomenon bears a resemblance to those cases of chemical combination in which the constituent elements change their sensible properties when they form the compound.

429. **Latent heat rendered sensible by congelation.**—If it be true that water is formed by the combination of a large quantity of heat with ice, it would necessarily follow that, in the reconversion of water into ice, or in the process of congelation, a corresponding quantity of heat must be disengaged. This fact can be easily established by reversing the experiment just described.

Let us suppose that a vessel containing water at 60° is immersed in a bath of mercury at the temperature of 60° below the freezing point. If one thermometer be immersed in the mercury and another in the water, the former will gradually rise and the latter fall, until the latter indicates 32°. This thermometer will then become stationary, and the water will begin to freeze; meanwhile the thermometer immersed in the mercury will still rise, proving that the water while it freezes continually imparts heat to the mercury, although the thermometer immersed in the freezing water does not fall. When the congelation is completed, and the whole quantity of water is reduced to the solid state, then, and not until then, the thermometer immersed in the ice will again begin to fall. The thermometer immersed in the mercury will rise without interruption, until the two thermometers meet at some temperature below 32°.

430. It is evident from this, that the heat which was latent in the water while in the liquid state is gradually disengaged in the process of congelation; and since the temperature of the ice remains the same as that of the water before congelation, the heat thus disengaged must pass to some other object, which in this case is the mercury.

When congelation takes place under ordinary circumstances, the latent heat which is disengaged from the water which becomes solid is in the first instance imparted to the water which remains in the liquid state. When this water passes into the solid state,

the heat which is disengaged from it is transmitted to the adjacent water which remains in the liquid state; and so on.

431. **Other methods of determining the latent heat of water.**—The latent heat of water may be further illustrated experimentally as follows. Let two equal vessels, one containing a pound of ice at 32°, and the other containing a pound of water at 32°, be both immersed in the same mercurial bath, maintained by lamps or otherwise at the uniform temperature of 300°, and let thermometers be placed in the ice and the water. The ice will immediately begin to melt, and the thermometer immersed in it will remain stationary. The thermometer immersed in the water will, however, at the same time begin to rise. When the liquefaction of the ice has been completed, and the thermometer immersed in it just begins to rise, the thermometer immersed in the water will be observed to stand at 174°·65. It follows, therefore, supposing the ice and the water to receive the same quantity of heat from the mercury which surrounds them, that as much heat is necessary to liquefy a pound of ice as is sufficient to raise a pound of water from 32° to 176°·65, which is 142°·65; a result which confirms what has been already stated.

432. The following experiment will further illustrate this important fact.

First let a pound of ice at 32° be placed in a vessel, and let a pound of water at 174°·65 be poured into the same vessel. The hot water will gradually dissolve the ice, and the temperature of the mixture will rapidly fall; when the ice has been completely dissolved, the water formed by the mixture will have the temperature of 32°. Thus, although the pound of warm water has lost 142°·65, the pound of ice has received no increase whatever of temperature. It has merely been liquefied, but retains the same temperature as it had in the solid state.

That it is the process of liquefaction alone which prevents the heat received by the ice when melted from being sensible to the thermometer, may be proved by the following experiment.

Let a pound of water at 32° be mixed with a pound of water at 174°·65, and the mixture will have the temperature of 103°, exactly intermediate between the temperatures of the compounds. But if the pound of water at 32° had been solid instead of liquid, then the mixture would have had, as already explained, the temperature of 32°. It is evident, therefore, that it is the process of liquefaction, and it alone, which renders latent or insensible all that heat which is sensible when the pound of water at 32° is liquid.

433. **Liquefaction and congelation always gradual.**—It was formerly supposed that water at 32° would pass at once from

the liquid to the solid state, on losing the least portion of heat; and that, on the other hand, a mass of ice would pass instantly from the solid to the liquid state, on receiving the least addition of heat. What has been just explained, however, shows that this sudden transition from the one state to the other cannot take place.

434. When a mass of water losing heat gradually is reduced to 32°, small portions of ice are formed, which give out their latent heat to the surrounding liquid, and for the moment prevent its congelation. As this liquid parts with its heat to surrounding objects, more ice is formed, which, in like manner, disengages its latent heat, and communicates it to a portion of the water still remaining liquid, thus tending to raise its temperature and keep it in the liquid state. The rapidity of the congelation will depend on the rate at which the uncongealed portion of the water can impart its heat to the surrounding air and other adjacent objects.

The same principles explain the gradual process of the liquefaction of ice. A small portion of ice first receives heat from some external source, and having received as much heat as would raise its own weight of water through 142°·65 of the thermometric scale, it becomes liquid. Then an additional portion of ice receives the same addition of heat, and is likewise rendered liquid; and so the process goes on, until the whole mass of ice is liquefied.

435. It is possible, under certain circumstances, to maintain water in the liquid state below the freezing point. If a vessel of water be carefully covered up, free from agitation, and exposed to a temperature of 22°, it will gradually fall to that temperature, still remaining in the liquid state; but if it be agitated, or a particle of ice or other solid body be dropped into it, its temperature will suddenly rise to 32°, and a portion of it will be converted into ice.

436. To explain this singular fact, it must be considered that the portion of the liquid which is thus suddenly solidified disengages its latent heat, which is communicated to that part of the water which still remains liquid, and raises it from 22° to 32°, and the remainder of the heat thus disengaged becomes sensible, instead of being latent in the ice itself, whose temperature it raises from 22° to 32°.

It follows, from what has been already explained, that the entire quantity of latent heat disengaged in this case would be sufficient to raise as much water as is equal in weight to the ice which has been formed through 142°·65, or, what is the same, it would raise 14¼ times this quantity of water through 10°. Now, in the present case, the whole quantity of water in the vessel, including the frozen part, has in fact been raised 10°, and it would follow,

therefore, that the frozen portion should constitute one part in $14\frac{1}{4}$ of the whole mass.

This test of the quantity of latent heat of water was applied with complete success, experimentally, by Dr. Thomson, who showed that when water cooled without congelation to 22° was suddenly agitated, a portion was congealed, which bore the proportion to the whole quantity just mentioned; that is to say, 10 parts in 142·65 of the entire mass. He found, likewise, that the same result was obtained when the water was cooled to any other temperature below 32° without congelation. Thus, when water cooled to the temperature of 27° without congelation was agitated, it was found that the 28·5 part of the whole mass was congealed. In this case the whole mass was raised through 5°; and since the heat developed by the frozen portion would be sufficient to raise $28\frac{1}{2}$ times this portion through 5°, it follows that the frozen portion must be the 28·5 part of the whole mass.

437. **Useful effects produced by latent heat.**—The great quantity of heat absorbed by ice when it melts, and given out by water when it freezes, subserves to the most important uses in the economy of nature. It is from this cause that the ocean, seas, and other large natural collections of water are most powerful agents in equalising the temperature of the inhabited parts of the globe. In the colder regions, every ton of water converted into ice gives out and diffuses in the surrounding region as much heat as would raise a ton of liquid water from 32° to 174°·65; and, on the other hand, when a rise of temperature takes place, the thawing of the ice absorbs a like quantity of heat: thus, in the one case, supplying heat to the atmosphere when the temperature falls; and, in the other, absorbing heat from it when the temperature rises. Hence we see why the variations in climate are less on the sea-coasts and on islands than in the interior of large continents.

The temperature of the air under the line does not vary much more than 4°, and that of the water varies not more than 1°.

438. **Latent heat of other bodies.**—The thermal phenomena explained above with reference to water belong to a general class, and are common, with certain modifications, to all solids which are transformed into liquids by the addition, and to all liquids which are transformed into solids by the abstraction, of heat. Thus, if a mass of tin have its temperature raised by the addition of heat until it attain the temperature of 442°, it will then become stationary, notwithstanding it receive further increments of heat; but the moment it becomes stationary, its fusion will begin, and it will continue steadily at the temperature of 442° until it be completed; but the moment the last particle of tin has been melted, its temperature will begin to rise.

In the same manner, if lead be submitted to an increase of temperature, it will begin to liquefy when it reaches the temperature of 594°; and notwithstanding the additional quantities of heat imparted to it, its temperature will not rise above 594° until its fusion is completed. In a word, all metals whatever, and in general all solids which by elevation of temperature are fused, undergo, during the process of fusion, no elevation of temperature; the heat imparted to them during this process becoming latent in them, since it does not affect the thermometer.

439. **Latent heat of fusion.** — This heat is called the *latent heat of fusion*, and its quantity for each body is determined by means similar to those already explained for water.

440. **Points of fusion.** — Different solids are fused at different temperatures, but the same solid is always fused at the same temperature, which temperature is called its *point of fusion*. This point of fusion constitutes, therefore, a specific character of the solid. The quantity of heat rendered latent during the fusion of different metals is different, but always the same for the same metal. This quantity is estimated or expressed by the number of degrees which it would raise the same weight of the same body, supposing it not to undergo the change from the solid to the liquid state. In the same manner, all liquids which, by the loss of heat, are converted into solids, have a certain point, the same for each liquid, but different for different liquids, at which they pass into the solid form. This point is called their *point of solidification*, or their freezing point. It is customary to apply the latter term only to such bodies as at common temperatures are found in the liquid state.

The point at which a body in the liquid state solidifies is the same as that at which the same body in the solid state is liquefied; the points, therefore, of solidification or congelation are the same as the points of fusion or liquefaction for the same bodies. Thus, the point of fusion for ice is the same as the freezing point for water.

Two conditions are therefore necessary to the fusion of a solid body: first, its temperature must be raised to the point of fusion; and, secondly, it must receive a certain quantity of heat, called its heat of fusion, which will become latent in it when the fusion has been completed.

In like manner two conditions are necessary to the congelation or solidification of a liquid: first, it must be reduced to its freezing point; and, secondly, it must be deprived of a certain quantity of heat, which exists latent in it, and maintains it in the liquid state.

In the following table are given the points of fusion of the several bodies named in the first column: —

The authorities are indicated as follows:—

Clarke, Cl.	Irvine, I.
Pouillet, P.	Ermann, E.
Vauquelin, V.	Crichton, Cr.
Daniell, Da.	Dumas, Du.
Murray, M.	Gay Lussac, G. L.
Guyton Morveau, G.	Thénard, T.

441. *Table showing the Point of Fusion of various Substances in Degrees of Fahrenheit's Thermometer.*

Names of Substances.	Deg. of Fahr.	Authorities.
Platina - - -	3082°	Cl.
English wrought iron	2912	P., V.
French ditto	2732	P.
Steel (least fusible) -	2552	
„ (most fusible) -	2372	
Cast manganese -	2282	
„ brown, fusible -	2192	
„ „ very fusible	2012	
„ white, fusible -	2012	
„ „ very fusible	1922	
Gold, very pure -	2282	
„ money - -	2156	
Copper - - -	1922	
Brass - - -	1859	Da.
Silver, very pure -	1832	P.
Bronze - - -	1652	
Antimony - -	810	
Zinc - - -	700 705 680	M. G. P.
Lead - -	608 590 592	P. I. G.
Bismuth - -	509 505 477 480	E. P. I. C.
Tin - - -	512 446 442 433	G. P. C. E.
Alloy 5 parts tin, 1 part lead - -	381	P.
Alloy 4 parts tin, 1 part lead - -	372	
Alloy 3 parts tin, 1 part lead - -	367	
Alloy 2 parts tin, 1 part lead - -	385	
Alloy 1 part tin, 1 part lead - -	460	
Alloy 1 part tin, 3 parts lead - -	552	

Names of Substances.	Deg. of Fahr.	Authorities.
Alloy 3 parts tin, 1 part bismuth -	392°	P.
Alloy 2 parts tin, 1 part bismuth -	333·9	
Alloy 1 part tin, 1 part bismuth -	286·2	
Alloy 4 parts tin, 1 part lead, 5 parts bismuth - -	246	
Sulphur - -	237 226	Du.
Iodine - - -	225	P.
Alloy 2 parts lead, 3 parts tin, 5 parts bismuth - -	212	
Alloy 5 parts lead, 3 parts tin, 8 parts bismuth - -	212	
Alloy 1 part lead, 1 part tin, 4 parts bismuth - -	201	
Soda - - -	194	G. L., T., P.
Potash - -	162 136	G. L., T. P.
Phosphorus -	109 100	 M.
Stearic acid - -	158	P.
Wax, bleached -	154	
„ unbleached -	142	
Margaric acid -	131 to 140	
Stearine - -	120 to 109	
Spermaceti - -	120	
Acetic acid - -	113	
Tallow - - -	92	
Ice - - - -	32	
Oil of turpentine -	14	
Mercury - - -	−38·2	

442. The latent heat of fusion has not been so extensively investigated. M. Person has, however, determined it for the bodies named in the following table. The points of fusion observed by M. Person, for the specimens tried, are given. The unit of the numbers expressing the latent heat is, in this case, the quantity of heat necessary to raise the same weight of water from 32° to 33°.

Names of Substances.	Points of Fusion.	Latent Heat for Unity of Weight.	Names of Substances.	Points of Fusion.	Latent Heat for Unity of Weight.
Chloride of lime -	83·3	72·42	Tin - - -	455·0	25·74
Phosphate of soda	97·5	120·24	Bismuth - -	518·0	22·32
Phosphorus -	111·6	8·48	Nitrate of soda -	590·9	113·36
Bees-wax yellow)	143·6	78·32	Lead - - -	629·6	9·27
D'Arcet s alloy -	204·8	10·73	Nitrate of potash -	642·2	83·12
Sulphur - -	239·0	16·51	Zinc - - -	793·4	49·43

443 **Facility of liquefaction proportional to the quantity of latent heat.** — The different quantities of latent heat peculiar to different bodies, explain the different degrees of facility with which they are liquefied. Ice liquefies very slowly, because its latent heat is considerable. Phosphorus and lead, on the other hand, whose latent heat is small, melt very rapidly. Ice cannot be liquefied until it has received as much heat as would raise its own weight of water 142·65; while lead and phosphorus are liquefied by as much heat as would raise their own weight of water 9°. Hence it will be understood why it is that glaciers and vast depths of snow continue on mountain ridges, such as the Alps, in spite of the heat imparted to them during the hottest summers; such heat, however considerable, being only sufficient to liquefy a portion of their superficial strata, which descends the declivities, and feeds the streams and rivers of which they are the sources.

444. The circumstance of water continuing in the liquid state below its freezing point, when kept free from agitation, is not peculiar to that liquid. Tin fused in a crucible was cooled by Mr. Crichton 4° below its melting point, and yet remained liquid; and similar phenomena have been observed with other metals. In all such cases, the moment solidification commences, the liquid, as in the case of water, suddenly rises to its point of fusion; and the same causes in all cases favour solidification.

445. **Refractory bodies.** — Bodies which are difficult of fusion are called refractory bodies. Among these, one of the most remarkable is carbon or charcoal, one form of which is the precious stone called the diamond. No degree of heat, as yet attained, has reduced this substance to the liquid state; indeed, diamond being crystallised charcoal, it is probable that if the fusion of charcoal could be effected, diamonds could be fabricated. Among the most refractory bodies are the earths, such as lime, alumina, barytes, strontia, &c. Of the metals, the most refractory are iron and platinum, but both of these are fused by the oxyhydrogen blowpipe, as well as by the galvanic current.

446. **Alloys.** — It is found that alloys composed of the mixture of two or more metals, in certain proportions, frequently liquefy at a much lower temperature than either of their constituents.

Thus a solder composed of 4 parts of lead and 6 of tin fuses at 336°. An alloy composed of 8 parts of bismuth, 5 of lead, and 3 of tin, liquefies at a temperature below that of boiling water; and an alloy composed of 496 bismuth, 310 lead, 177 tin, and 26 mercury, fuses at 162°·5. If a thin strip of this alloy be dipped into water that is nearly boiling hot, it will melt like wax.

447. Some bodies, like water, pass from the complete solid to the complete liquid state without passing through any intermediate degrees of aggregation, while others, like wax, tallow, and butter, become soft at temperatures considerably below those at which they are liquefied; and there are others, like glass and some of the metals, which never, at any temperature, attain absolute fluidity.

448. **Sulphur.** — Sulphur also presents some curious exceptional circumstances in its state of aggregation at different temperatures. If heat be gradually and slowly imparted to it, it will be fused, and become very fluid at 302°. If the supply of heat be continued, it will change its colour, and become red and viscous and considerably less fluid. At length, heat being further supplied, and its temperature being raised from 430° to 480°, it will become altogether red, opaque, and acquire the consistency of a thick paste.

449. The freezing points of liquids are generally lowered when solids are dissolved in them. Thus, when salt is dissolved in water, the freezing point of the solution is always below 32°, and its distance below it depends on the quality and quantity of salt in solution.

450. **Acid solutions.** — The strong acids generally freeze at much lower temperatures than water; and if they be mixed with water, the freezing point of the mixture will hold an intermediate position between those of water and the pure acid. The freezing points of the acids themselves vary with their strength, but not according to any known or regular law.

451. **Sudden change of volume.** — When a liquid passes into the solid state by the absorption of heat, a sudden and considerable change of dimensions is frequently observed. This change is sometimes an increase and sometimes a diminution, and in some cases no change takes place at all. When mercury is cooled to its freezing point, which is —39°, it undergoes an instantaneous and considerable diminution of bulk as it passes into the solid state. An effect exactly the reverse takes place with water. When this liquid cools down to 32°, it passes into the solid state, and in doing so undergoes a considerable and irresistible expansion. So great is this expansion, and so powerful is the force with which it takes place, that large rocks are frequently burst when water collected in their crevices freezes. It is a common occurrence that glass

bottles containing water, left in dressing-rooms in cold weather, in the absence of fire, are broken when the water contained in them freezes, the expansion in freezing not being yielded to by any corresponding dilatation in the glass. An experiment was made at Florence on a brass globe of considerable strength, which was filled with water, and closed by a screw. The water was frozen within the globe, by exposure to a cold below 32°, and in the process of freezing the water burst the globe. It was calculated that the force necessary to produce this effect amounted to about 28000 lbs.

452. This sudden expansion of water in freezing is a phenomenon distinct from the expansion already noticed, which takes place as the temperature is lowered from 38°·8 to 32°. The latter expansion is gradual and regular, and accompanied by a gradual and regular decrease of temperature; but, on the other hand, the expansion which takes place when water passes from the state of liquid to the state of ice is sudden and even instantaneous, and is accompanied by no change of temperature, the solid ice having the temperature of 32°, and the liquid of which it is formed having had the same temperature just before congelation.

453. When water is cooled below 32° without freezing, the expansion which took place from 38°·8 to 32° is continued, and the liquid continues to dilate below 32°: when it is afterwards solidified by agitation, or by throwing in a crystal of ice, a sudden and considerable expansion takes place as already described, but this expansion is always less than would take place if it solidified at 32°, by the quantity of expansion which it suffered in cooling from 32° to the temperature at which it was solidified. It is observed that the expansion which water suffers in being solidified at 32° amounts to about one seventh of its bulk. If it be solidified at a lower temperature, it will suffer a less expansion than this; but the expansion which it suffers in solidification under these circumstances, added to the expansion which it suffers in cooling from 32° downwards previous to solidification, it will always produce a total amount equal to the expansion which it would suffer in solidifying at 32°. Hence the total expansion which water undergoes. from the temperature of greatest density (38°·8) until it becomes solid, is always the same, whatever be the temperature at which it passes from the liquid to the solid state. The same observations will be likewise applicable to other liquids similarly solidified.

454. If a quantity of liquid phosphorus, at the temperature of 200°, be gradually cooled, it will be observed to suffer a regular contraction in its dimensions, according to the general laws observed in the cooling of bodies. When it is cooled to the temperature of about 100°, it passes into the solid state, and in doing

so undergoes a sudden and considerable contraction. Oils generally undergo this sudden contraction in the process of freezing.

455. It may be assumed as generally true, that bodies which crystallise in freezing undergo a sudden expansion, and that bodies that do not crystallise in freezing, for the most part suffer a sudden contraction. Sulphuric acid, however, is an example of a liquid which passes from the liquid to the solid state, and *vice versâ*, without any discoverable expansion or contraction. Most of the metals contract in passing from the liquid to the solid state, the exceptions being cast iron, bismuth, and antimony, all of which undergo expansion in solidifying.

456. It is evident that a metal which contracts in solidifying cannot be made to take the exact shape of the mould. It is for this reason that money composed of silver, gold, or copper cannot be cast, but must be stamped. Cast iron, on the contrary, as it dilates in solidifying, takes the impression of a mould with great precision, as do also certain alloys used in the arts.

457. The most striking instance of sudden contraction in cooling is exhibited in the case of mercury. This was first observed in the case of a thermometer, which, when exposed to a temperature about 40° below zero, was observed to fall suddenly through a considerable range of the scale, and in some cases the mercury was precipitated into the bulb. It was observed that the thermometer being exposed to a temperature lower than —40°, the mercury gradually falls until it arrives at about —38°, and that then a great and sudden contraction takes place at the moment the metal is solidified.

This contraction, however, must not be understood as indicating any real fall of temperature, as is the case with all the previous and regular contractions which take place before the solidification of the metal.

458. Substances which soften before they melt, and which pass by degrees from the solid to the liquid state, are mostly of organic origin, and their point of fusion is below the temperature of boiling water. Some of these, which are of most general utility in the arts, are the following:

Colophony,	begins	to melt at	275°
Brown wax	"	"	110
White wax	"	"	124
Tallow	"	"	104
Pitch	"	"	91

459. **Weldable metals.**—The metals capable of being welded soften before they are fused; and the heat at which they soften is called a *welding heat.* The metals which most readily admit of being welded are platinum and iron. At an incipient white heat (2372°) they become soft; and, in this state, pieces of the metal

may be intimately united when submitted to severe pressure, or when passed under the hammer.

460. **Freezing mixtures.**—It may be taken as a physical law of high generality, that a solid cannot pass into the liquid state without absorbing and rendering latent a certain quantity of heat. This heat may be, and often is, supplied from some other body in contact with that which is liquefied. But if no such external supply of heat be present, and if, nevertheless, any physical agency cause the liquefaction to take place, the body thus liquefied will actually absorb its own sensible heat. While it is liquefied, it will therefore fall in temperature to that extent which is necessary to supply its latent heat of fluidity at the expense of its sensible heat.

To render this more clear, let us imagine a pound of ice at the temperature of 32° to be mixed with a pound of liquid having the temperature of —103°, and let this liquid be supposed to have the property of dissolving the ice. When the liquefaction is completed, the temperature of the mixture will be —103°. Now the liquid, which is here supposed to be the solvent, neither imparts heat to the ice nor abstracts heat from it. The ice, therefore, now liquefied, contains exactly as much heat as it contained before liquefaction, and no more. But, to become liquid, it was necessary that 142°·65 of heat should be absorbed by it, and become latent in it. This 142°·65 has therefore been transferred from the sensible to the latent state in the ice itself.

This principle has been applied extensively in scientific researches and in the arts for the production of artificial cold, the compounds thus made being called *freezing mixtures*.

In all freezing mixtures, two or more substances are combined, one or more of which are solid, and which have chemical properties in virtue of which, when intimately mixed together, they enter into combination, and, in combining, liquefy. The operation is so conducted, that no heat is supplied either by the vessel in which the liquefaction takes place, or from any other external source. Such being the case, it follows that the heat absorbed in the liquefaction must be supplied by the substances themselves which compose the mixture, and which must therefore suffer a depression of temperature proportional to the quantity of heat thus rendered latent.

The cold produced will be increased by reducing the temperature of the substances composing the mixture before mixing them. Thus, let A and B be the substances mixed. Before being combined, let them be reduced to 32° by immersing them in snow. Let them then be mixed, and let the latent heat of fusion be 32°. The mixture will fall to zero, since the 32° of sensible heat will be

absorbed. But if, at the moment of mixing them, their temperature had been 64°, then the temperature of the mixture would become 32°.

The substances which may be used to produce freezing mixtures on this principle are very various.

If equal weights of snow and common salt at 32° be mixed, they will liquefy, and the temperature will fall to —9°.

If 2 lbs. of muriate of lime and 1 lb. of snow be separately reduced to —9° in this liquid and then mixed, they will liquefy, and the temperature will fall to —74°.

If 4 lbs. of snow and 5 lbs. of sulphuric acid be reduced to —74° in this last mixture, and then mixed, they will liquefy, and the temperature will fall to —90°.

If a pound of snow be dissolved in about two quarts of alcohol at 32°, the mixture will fall nearly to — 13°. If the same quantities of snow and alcohol, being reduced in this mixture to — 13°, be then mixed, the temperature of the mixture will be reduced to —58°; and the same process being repeated with like quantities in this second mixture, a further reduction of temperature to — 98° may be produced; and so on.

461. **Apparatus for producing artificial cold.**—Freezing mixtures are used for the artificial production of ice in hot climates. The most simple apparatus for this purpose is repre-

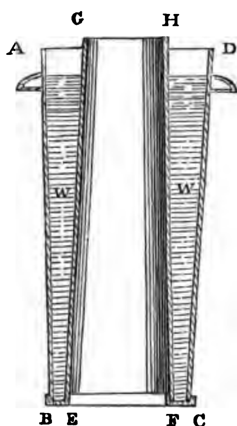


Fig. 246.

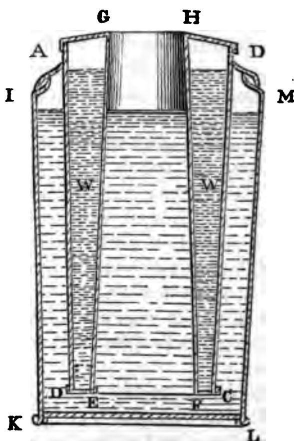


Fig. 247.

sented in *fig.* 246., and is composed of a tin bucket A B C D, having a slightly conical form, in the bottom of which is a circular hole,

a little less in diameter than the bottom. In this hole is soldered the mouth of another tin bucket, G E F H, also conical, but with its smaller end upwards. A space W is thus left between the two tin buckets, in which the water or other substance to be cooled is placed.

The freezing mixture is placed in another vessel, I K L M, (*fig.* 247.), similar in form to the bucket A B C D. This vessel I K L M ought to be made of some non-conducting material. Common glazed earthenware would answer the purpose. When the freezing mixture is placed in it, the vessel A B C D is immersed in it; so that the cold liquid is not only in contact with the external surface of the tin bucket A B C D, but also with the inner surface of G E F H. The water W, or whatever other substance it is required to cool, is therefore quickly reduced in temperature.

If it be not convenient to provide a vessel such as I K L M in earthenware, a tin vessel thickly coated with woollen cloth may be used.

462. **Table of freezing mixtures.**— There are a great variety of bodies which, by combination, serve for freezing mixtures. The following table has been collected from the results of the researches of Walker and Lowitz. The substances are indicated by letters as follows: —

Water - - -	W	Nitrate of potash - -	NP
Snow, or ice - - -	I	„ ammonia - -	NA
Sulphate of ammonia - -	SA	Sulphuric acid - -	SA
„ soda - -	SS	Nitric acid - - -	NA
Muriate of ammonia - -	MA	Hydrochloric acid - -	HA
„ soda - -	MS	Dilute - - -	d
„ lime - -	ML	Crystallised - - -	c
Carbonate of soda - -	CS		

The figures prefixed indicate the proportion by weight in which the ingredients are mixed. Thus, 6SS+4MA+2NP+4dNA signifies a mixture of 6 oz. of sulphate of soda, 4 oz. of muriate of ammonia, 2 oz. of nitrate of potash, and 4 oz. of dilute nitric acid.

	From	To	Cold produced.
5 MA+5 NP+16 W -	+50°	+10°	40°
5 MA+5 NP+8 SS+16 W - - -	+50	+ 4	46
1 NA+1 W - -	+50	+ 4	46
1 NA+1 CS+1 W -	+50	− 7	57
3 SS+2 dNA - -	+50	− 3	53
6 SS+4 MA+2 NP+4 dNA - -	+50	−10	60
6 SS+5 NA+4 dNA -	+50	−14	64
9 PS+4 dNA - -	+50	−12	62
9 PS+6 NA+4 dNA-	+50	−21	71
8 SS+5 HA - -	+50	0	50
5 SS+4 dSA - -	+50	+ 3	47
2 I+1 MS - - -	x	− 5	
5 I+2 MS+1 MA -	x	−12	
24 I+10 MS+5 MA+5 NP - - -	x	−18	

	From	To	Cold produced.
12 I+5 MS+5 NA -	x	−25°	
3 I+2 dSA - -	+32°	−23	55°
8 I+5 HA - -	+32	−27	59
7 I+4 dNA - -	+32	−30	62
4 I+5 ML - -	+32	−40	72
2 I+3 cML - -	+32	−50	82
3 I+4 NP - -	+32	−51	83
5 PS+3 NA+4 dNA	0	−34	34
3 I+2 dNA - -	0	−46	46
8 I+3 dSA+3 dNA -	−10	−56	46
1 I+1 dSA - -	−20	−60	40
3 I+4 ML -	+20	−48	68
2 I+3 ML - -	−15	−68	53
1 I+2 cML - -	0	−66	66
1 I+3 cML - -	−40	−73	33
8 I+10 dSA - -	−68	−91	23

463. Thirolier produced a powerful freezing mixture, by solidifying carbonic acid, and mixing it with sulphuric acid or sulphuric ether. A temperature 120° below zero, and therefore 152° below the freezing point, was thus produced.

Mitchel, repeating the experiment, produced a still more intense cold. He exposed alcohol of the specific gravity of 0·798 successively to the temperatures of −130° and −146°. He states that at the former temperature it had the consistency of oil, and at the latter resembled melting wax.

464. If these experiments can be relied on, it may be inferred that the freezing point of alcohol, so long and hitherto so vainly sought, is probably about −150°, or 182° below the freezing point of water and 110° below that of mercury.

465. To ensure success in experiments on extreme cold produced by freezing mixtures, the salts used must not have lost their water of crystallisation, because in that case they quickly absorb water, and converting it into ice liberate caloric and obstruct the cooling. The salts and ice used should be pulverised so as to dissolve quickly. When extreme cold is required, the vessel containing the freezing mixture should be immersed in another vessel, containing also a freezing mixture, so as to retard the mixture under experiment from receiving heat from the vessel which contains it, and a sufficient quantity of the ingredients forming the freezing mixture should be used.

466. The greatest natural cold of which any record has been kept, was that observed by Professor Hanstean between Krasnojarsk and Nishne-Udmiks in 55° N. lat., which he states amounted to −55° (Reaum.?) = −91·75 F.

At Jakutsk, the mean temperature of December is −44½° F. In 1828, from January 1. to January 10., the mean temperature of that place was −58°.

In the expedition to Khiva, in December 1839, the Russian army experienced for several successive days a temperature of −41°·8 F.

467. **Principle of fluxes.** — The same principle which explains the effect of freezing mixtures, is also applicable to the phenomena attending fluxes in metallurgy. *Fluxes* are certain bodies which, when mixed with others, cause them to fuse at lower temperatures than their proper point of fusion. It is by this means that certain metals and metallic ores are fused, when exposed to the operation of blast furnaces. In a certain sense, salt may be said to be a flux for ice; but this term flux is usually limited in its application to bodies which are only fused at very elevated temperatures: for example, in enamelling, and in the manufacture of glass and of the paste by which precious stones are imitated, siliceous sand is em-

ployed in greater or less proportion, about one third for enamel, and nearly three fourths for plate glass. Now silica is not fused at any heat attainable by common furnaces. M. Gaudin lately succeeded in its fusion, by means of the oxy-hydrogen blow-pipe, and drew it into threads as fine as the filaments of silk. When combined, however, with proper fluxes, it fuses readily in the furnace. The fluxes used vary according to the purposes for which the silica is applied, but they consist generally of soda, potash, and lime, with the addition of lead for flint glass, and stannic acid for enamel. The compound which results from the mixture of these ingredients, by their exposure to intense heat, is reduced to a sort of pasty fusion, but can never be said to undergo positive liquefaction. Nevertheless, the beautiful transparency of Bohemian glass, plate glass, flint glass, and the factitious diamonds, show that the constituents must be combined in a very intimate manner.

Fine earthenware and porcelain are also fabricated by means of fluxes; for although fusion is not actually produced, nor is there the same intimate combination of the constituents as takes place in vitrefaction, still there is a partial combination, and an incipient fusion. The fluxes in this case consist also of soda, potash, lime, and sometimes magnesia, the soda and potash, however, being used in heir combined form of feldspar.

468. Infusible bodies may be resolved into two classes, those which are refractory, and which alone can be properly said to be infusible, and those whose fusion is prevented by their previous chemical decomposition or composition. Before the invention of the oxy-hydrogen blow-pipe, and other scientific expedients for the production of intense heat, the number of refractory substances was much more considerable than it is at present. Scarcely any body can be said to be absolutely infusible except charcoal, which under all its forms of pure carbon, anthracite, graphite, and diamond, has resisted fusion at the highest temperature which has yet been produced.

The term, refractory, however, is still applied to those classes of substances which resist fusion by ordinary furnaces.

When certain compound bodies are exposed to an intense heat, they are resolved into their constituents before they attain the point of fusion; and in other cases simple bodies enter into chemical combination with others which surround them, or are in contact with them before the fusion takes place.

The fusion, however, may in some cases of both of these classes of bodies be effected by confining them in some envelope which will resist the separation of their constituents if they be compound, or exclude them from contact with bodies with which they might combine if they be simple.

469. If marble be exposed under ordinary circumstances to an intense heat, it will be resolved into its constituents, lime and carbonic acid; but if it be confined in a strong gun-barrel, for example, it may be fused.

470. Almost all organic solids, except the resins and the fats, are infusible before they are decomposed; we cannot melt a piece of wood, a leaf, a flower, or a fruit; but after having evaporated their liquid constituents, and dried them, the influence of heat causes their constituents to enter into combination, and produces new substances, which are generally volatile, and which have nothing in common with the original substances.

471. When water holding any body in solution has its temperature sufficiently lowered, its congelation takes place in one or other of three ways: first, the water may congeal independently of the body which it holds in solution; secondly, the body which it holds in solution may congeal, leaving the water still liquid; thirdly, the water and the body it holds in solution may congeal together.

The congelation of the water independent of the substance it holds in solution is presented in the case of the very weak solutions. In this case, the point of congelation is always below the freezing point. Thus, if water holds in solution a small quantity of alcohol, acid, alkali, or salt, it will be necessary to reduce the whole to the freezing point to produce its congelation; but when ice has been formed upon it, this ice will consist of pure water, without the mixture of any portion of the substances which the water held in solution. Thus, sea-water freezes at $27\frac{1}{2}^\circ$, being $4\frac{1}{2}^\circ$ degrees below the freezing point of pure water; and if the ice produced upon it be withdrawn and melted, it will produce pure water. In the same manner, if weak wine be frozen, the ice formed upon it will be the ice of pure water, and the wine which still remains liquid will be proportionally stronger. This method is sometimes practised to give increased strength to wine.

472. Water is generally capable of holding in solution only a certain quantity of any solid substance, and when all the substance has been dissolved in it which it is capable of taking, the solution is called a saturated solution. Now, it is found that the quantity of solid matter of any kind which water is capable of holding in solution, increases with the temperature. Thus, water at 212° will hold more of any given salt in solution, than would water at 50°. Let us suppose, then, that a saturated solution of any salt is made at 200°. If this solution be allowed to cool, a part of the salt which it contains must return to the solid state, since at lower temperatures it cannot hold in solution the same quantity; and in proportion as the temperature of the solution falls, the quantity of solid matter which will be formed in it will increase. In this

case, the cooling produces a partial decomposition of the solution. If the cooling be accomplished suddenly, the salt is precipitated tumultuously and in a confused mass, without form or cohesion; but if the solution is allowed to cool slowly and without agitation, the molecules of the salt collect into regular crystals.

Even after the temperature of the solution has ceased to fall, the decomposition and crystallisation will continue, if the vessel containing the solution be in a position favourable to superficial evaporation. The water which evaporates from the surface taking with it none of the salt, all that portion of salt with which it was combined will receive the solid form, and will collect into crystals; and this process may be continued until, by superficial evaporation, all the water shall have disappeared, and nothing be left in the vessel except a collection of crystals of the salt.

473. The solution of anhydrous sulphate of soda presents some remarkable exceptional phenomena. At the temperature of $91^{\circ}\cdot4$ it has a maximum of saturation; that is to say, above this point, as well as below it, the proportion of salt which it contains diminishes. However, at the boiling point, it contains much more salt than at the common temperature. If the solution be boiled in a large tube, and when it is well purged of air the tube be closed at the top, so as to exclude the atmosphere, the cooling will take place without any solidification; but when the top of the tube is broken so as to admit the air, the salt is suddenly congealed in a mass, with so great a disengagement of heat, that the tube becomes warm to the touch.

474. In some cases the water and the salt which it holds in solution are solidified together. This happens when the salts contain their water of crystallisation. The phenomena are produced in the same manner as in the case just described, with this difference, that the molecules of salt, in collecting, carry with them the molecules of the water of crystallisation, which pass also to the solid state, taking the place which belongs to that in the crystals. Nevertheless, the solidification of the water disengaging in general much more latent heat than the solidification of the salt, the crystals undergo a less rapid increase, whether formed by mere cooling, or by evaporation of a part of the dissolving mass.


Fig. 248.

475. **Dutch tears.** — When bodies liquefied by heat are suddenly cooled, some remarkable and exceptional phenomena are often produced. Thus, if large drops of glass in a state of fusion be let fall into a vessel of cold water, the solidification of their superficial parts is immediate; that of their interior is much more slow. There results from this a sort of forced and unnatural arrange-

ment of the molecules of the drop, which explains the singular phenomenon produced by Dutch Tears, so called from the form they assume, as represented in *fig.* 248. If the extremity of the tail of one of these be broken, in an instant the entire mass cracks, and is reduced to powder. This arises from the fact that, the glass not being cooled slowly and gradually, the molecules in solidifying have not had time to assume their natural position, and, being in a forced position, on the least disturbance separate.

476. **Annealing.** — To prevent this, articles manufactured of glass are submitted to the process called annealing after their fabrication; — a process in which, being again raised to a certain temperature, they are allowed to cool very slowly. Pottery in general is submitted to the same process.

477. **Tempering steel.** — The temper of steel is a quality analogous to this. Being heated almost to the point of fusion, and being plunged in water, it becomes as brittle as glass. In this state it is said to have the highest temper. If it is tempered only at a cherry red, it is less hard and less brittle. This is what is called the ordinary temper. In short, it may be annealed in an infinite variety of degrees over a fire of small charcoal, according to the temper which it is desired to impart to it. The oxydation which it suffers at the surface indicates, by the colour which it gives to it, the degree of annealing which it has received. Thus, it sometimes acquires a blue colour, and sometimes a straw colour; the latter colour indicating a harder and less elastic quality.

CHAP. VI.

VAPORISATION AND CONDENSATION.

478. **Evaporation in free air.** — If a liquid be exposed in an open vessel, it will be gradually converted into vapour, which, mixing with the atmosphere, will be dissipated, and after a certain time the liquid will disappear. This phenomenon, called evaporation, was formerly explained by the supposition that the air had a certain affinity for the liquid in virtue of which the air *dissolved* it, just as water dissolves sugar or salt.

A conclusive proof of the falsehood of this hypothesis was presented by the fact that the vaporisation of the liquid takes place in a vacuum, and that the presence of air not only does not cause more of the liquid to be evaporated than would have been evapo-

rated in its absence, but actually retards and obstructs the evaporation.

479. To be enabled to examine and observe with clearness and precision the mechanical properties of the vapour of any liquid, it is necessary to provide means by which such vapour can be separated from air and all other gases and vapours, since, being mixed with these, its properties would be modified, so that it would be difficult to determine what effects are due to the vapour, and what to the gases with which it is combined.

This object has been attained by apparatus, the principle of which we shall now explain.

Let A B (*fig.* 249.) be a glass bulb and tube, the bore of the tube being very small compared with the capacity of the bulb. Let the tube be widened into a sort of bell-shaped mouth at the end B, and let a graduated scale be engraved upon it, the zero being near the bulb.

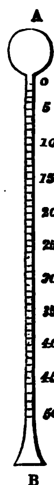


Fig. 249.

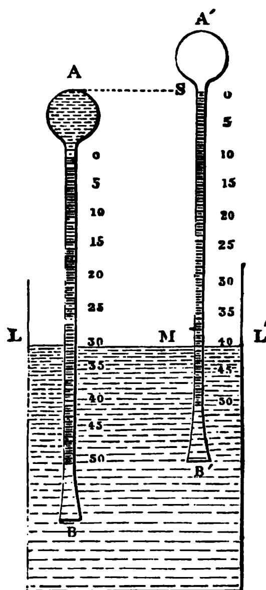


Fig. 250.

Let the tube, held with the open end B upwards, be filled with pure mercury well purged of air, as described in (215.) *et seq.*

Placing the finger on B to prevent the escape of the mercury or the entrance of air, let the tube be inverted, and the end B immersed in a trough of mercury, as represented in *fig.* 250. If it be immersed to such a depth that the height of the top of the bulb A above the level L L′ of the mercury in the trough is less than the height of the barometric column, the mercury will not fall from the bulb, being sustained there by the atmospheric pressure.

But if the bulb be raised to a greater height A′ above L L′, the column of mercury will not rise with it, but will stand at the height of the barometric column.

Let the bulb be raised to such a height A′ that the zero of the scale engraved on the tube shall be at a height above L L′ equal to the barometric column. In that case the level of the column of mercury in the tube will coincide with the zero of the scale, and the space in the bulb and tube above this level will be a vacuum. Let this space be S A′, and let S M represent the column of mercury which corresponds in height with the barometer.

Let C D (*fig.* 251.) be a small iron cylinder containing mercury, above which is a piston by which it can be pressed downwards. This piston is urged by a screw, so as to be capable of being moved with accuracy through any proposed space, however small. Attached to the bottom of the cylinder C D is a very fine tube D P, bent into a rectangular form so as to present its mouth upwards. This capillary tube is filled with the liquid, the vapour of which it is desired to submit to observation. By means of the screw acting on the piston, any proposed quantity of this liquid can be expelled from the mouth P of the tube.

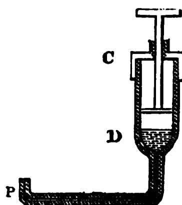


Fig. 251.

This instrument being immersed in the trough L L′ (*fig.* 250.), and the mouth of the tube P being directed into the bell-shaped end of the tube B, a certain small quantity of the liquid is expelled by means of the screw, and issues from P. It rises by its relative levity through the mercury, and arrives at the top S of the column. There it *instantly disappears*, and at the same time the mercury falls to a lower level.

480. **Vapour of a liquid an elastic, transparent, and invisible fluid like air.** — The cause of this will be easily understood. The minute drop of liquid which rises to the surface is converted into vapour on arriving there, and is diffused in that state throughout the entire capacity of the tube and bulb. It is transparent and invisible like air; and therefore, notwithstanding

its pressure, the bulb and tube appear to be empty, as they would if they were filled with air.

481. **How its pressure is indicated and measured.**—But this vapour being, like air, an elastic fluid, exercises a certain pressure upon the mercurial column S M, which pressure is manifested and measured by the fall of that column. The summit, which before stood at the zero of the scale, now stands at a lower point, and the number of the scale indicating its position, expresses the pressure of the vapour in inches of mercury. Thus, if the summit S of the column stand at half an inch below zero, the pressure of the vapour in the bulb is such as would support a column of mercury half an inch in height.

Now let us suppose another small drop of the liquid to be injected by the apparatus *fig.* 251. Like effects will ensue, and the summit S of the column will fall still lower, showing that the pressure of the vapour is augmented.

482. **Saturated space.**—By repeating this process, it will be found, that when a certain quantity of the liquid has been injected, no more vapour will be produced, and the liquid will float on the summit S of the mercurial column without being vaporised. The summit of the column will not be further depressed.

It appears, therefore, that the space in the bulb and tube is then *saturated* with vapour. It has received all that it is capable of containing. That this is the case will be rendered manifest by elevating the tube. The summit S of the column still maintaining its height above L L′, a greater space will be obtained above S, and it will be accordingly found that a portion of the liquid which previously floated on S will be vaporised; and if the tube be still more elevated, the whole will disappear.

Since during this process the height S M of the mercurial column in the tube remains unaltered, it follows that the pressure of the vapour remains the same.

By comparing the volume of the liquid ejected from P, *fig.* 251., with the volume of the tube and bulb filled by the vapour into which it is converted, the density of the vapour, or, what is the same, the column of vapour into which one unit of volume of the liquid is converted may be ascertained.

There are, however, other circumstances connected with this process, which are not rendered apparent, and which it is important to observe and comprehend.

When the liquid rises to the surface of the mercurial column and expands into vapour, it absorbs a certain quantity of heat which becomes latent in it. This heat must be supplied by the tube, the bulb, and the mercury; and as the temperature of these does not permanently fall, this heat is replaced, and their tempera-

ture restored by the surrounding air. The quantity of heat absorbed in the evaporation of the liquid will be presently shown. Meanwhile it must be observed that the supply of the latent heat is essential to the evaporation of the liquid. If the mercury on which the liquid floats, and the glass by which it is inclosed, were absolute non-conductors, and could impart no heat whatever to the liquid, then the evaporation could not take place.

It appears from what has been explained, that when the space above the mercury has been charged with a certain quantity of liquid in the state of vapour, or, what is the same, when the vapour it contains has attained a certain density, all further evaporation ceases; and any liquid which may be injected will remain in the liquid state, floating on the mercury. So long as the temperature of the surrounding medium, and consequently that of the bulb and its contents, remains unaltered, and so long as any liquid remains floating on the mercury, the pressure and the density of the vapour in the bulb will be unaltered. If the bulb be raised, so as to give more space for the vapour, a proportionally increased quantity of the liquid will be vaporised; and if by depressing the tube the volume of the vapour be diminished, a corresponding part of it will return to the liquid state. In the one case, heat will be absorbed by the liquid evaporated; and in the other, heat will be developed by the vapour condensed. This heat is borrowed from the surrounding atmosphere in the one case, and imparted to it in the other; since, otherwise, the bulb and its contents must undergo a change of temperature, contrary to what was supposed.

483. **Quantity of vapour in saturated space depends on temperature.**—But let us now consider what will be the effect of raising or lowering the temperature of the bulb and its contents. The bulb being charged with vapour, and a stratum of unevaporated liquid floating on the mercury, let the temperature of the medium surrounding the bulb be raised through any proposed number of degrees of the thermometric scale. This will be immediately followed by the evaporation of a part of the liquid floating on the mercury, and a depression of the column. An increased volume of vapour is therefore now contained in the bulb and tube; but if this increase of volume be compared with the increased quantity of liquid evaporated, it will be found to be less in proportion; and it consequently follows that the density of the vapour is augmented; and since the column of mercury has been more depressed, and since this depression measures the pressure of the vapour, it follows that this pressure has been also augmented.

484. **Relation between pressure, temperature, and density.**—Thus it appears that the pressure and density of the

vapour produced from the liquid floating on the mercury are augmented as the temperature of the liquid is augmented, and consequently diminished as that temperature is diminished.

In short, a certain relation subsists between the temperature, pressure, and density, such that when any one of these are known, the other two can always be found. If this general relation were known, and could be expressed by an arithmetical formula, the pressure and density of the vapour corresponding to any proposed temperature, or the temperature corresponding to any proposed density and pressure, could always be ascertained by calculation. But the theory of heat has not supplied the means of determining this relation by any general principles; and, consequently, the pressures and densities of the vapour of liquids at various temperatures have been determined only by experiment and observation.

485. Different liquids at the same temperature produce vapours having different pressures and densities. A form of apparatus adapted to illustrate this experimentally is shown in *fig.* 252.

A series of glass tubes being filled with mercury and inverted in a cistern of that liquid, by the process already described in the case of a barometer tube, are mounted side by side, having a divided scale placed in juxtaposition with them. The mercury will then fall in each of them to the height at which it stands in the barometer.

One of the tubes being reserved as a barometric standard, a drop of each of the liquids to be examined is let into the others, when it will be observed that the moment the bubble of the liquid rises to the summit of the mercurial column, that column will instantly fall, and it will fall to different points in the several tubes, showing that at the same temperature the vapours of different liquids produced in a vacuum will have different pressures.

It is necessary to observe, however, that in the performance of this experiment a sufficient quantity of liquid must be introduced into each of the tubes to leave more or less of it unevaporated at the summit of the mercury, since otherwise the vacuum above the mercury would not be saturated with vapour.

486. Of all liquids, that of which the vaporisation is of the greatest physical importance, and consequently that which has been the subject of the most extensive system of observations, is water.

If water be introduced above the mercurial column in the apparatus above described, and be exposed successively to various temperatures, the pressures and densities of the vapour it produces can be observed and ascertained.

It is thus found that, in all cases, water passing into the vaporous state undergoes an enormous enlargement of volume,



Fig. 252.

and that this enlargement increases as the temperature at which the evaporation takes place is diminished. Thus, if the temperature be 212°, a cubic inch of water swells into 1696 cubic inches; and if the temperature be 77°, it swells into 23090 cubic inches of vapour.

487. There is no temperature, however low, at which water will not evaporate. If the bulb and tube be exposed to the temperature of 32°, the mercurial column in the tube will be lower than the barometric column by two tenths of an inch,—a small but still observable quantity; and even if the temperature be reduced still lower, so that the liquid floating on the mercury shall become solid ice, there will still be a vapour in the bulb of appreciable pressure and density. Thus, a piece of ice at the temperature of —4° (that is, 36° below the freezing point) produces a vapour whose pressure is represented by a column of mercury of a twentieth of an inch.

488. **The apparatus of Gay Lussac.** — This apparatus, to

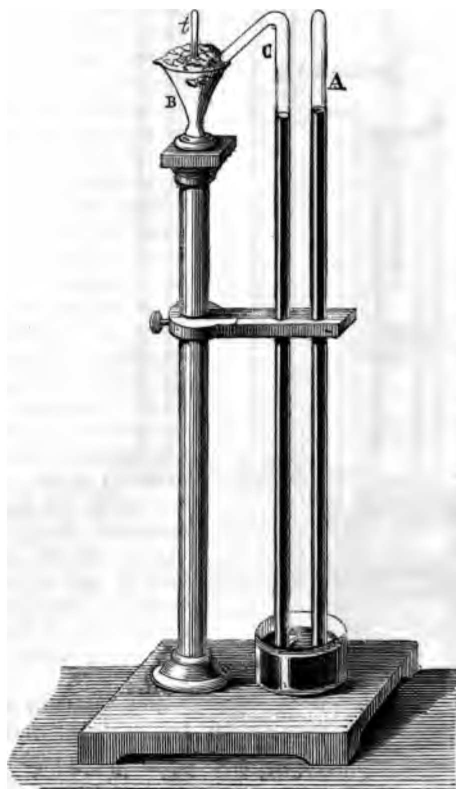


Fig. 253.

determine the pressure of the vapour of water below the freezing point, consisted of two barometric tubes, filled with mercury, and inverted in the usual manner in a cistern of that fluid, as shown in *fig.* 253. One of these, A, was used as a barometer, and the other, being curved at C, had its extremity immersed in a vessel containing a freezing mixture, in which was also plunged a thermometer, *t*, to show its temperature. A drop of water being then let in at the lower end of the bent tube in the usual way, the mercury in that tube will fall below its level in the tube A, by a quantity which will vary with the temperature of the freezing mixture in B.

This depression of the mercurial column in the tube C is produced by the pressure of the vapour evolved from the water which floats on the mercury in that tube. But this water is evidently not exposed to the same temperature as that part of its vapour which is enveloped in the freezing mixture, and it might therefore be supposed that the pressure indicated by the difference of the columns in the two tubes might be as well taken to be that corresponding to the water in the tube C, as that which would correspond to the temperature of the freezing mixture. But it will presently appear that when the vapour of a liquid communicates freely between two vessels, the temperature of one of which is lower than that of the other, the pressure of the vapour will correspond to the lower temperature.



Fig. 254.

489. **Dalton's apparatus.** — The apparatus (*fig.* 254.) with which Dalton ascertained the pressure of the vapour of water between

32° and 212°, consisted of two barometric tubes A and B, filled and inverted as usual, and plunged in a cistern F of mercury. A cylindrical glass vessel, open at both ends, and of sufficient capacity to include the two tubes surrounds them, and is also immersed in the mercury. This vessel is filled with water to a level above the tops of the tubes, and a thermometer D C, let into it, is supported above it; a charcoal furnace is placed under the mercurial cistern F, and a divided scale E, is placed beside the apparatus to indicate the heights of the column. Water is then let into one of the tubes B, the other A being reserved as a barometer, and the temperature of the mercury in F, and therefore of the water which rests upon it, being gradually elevated, the mercury in B will fall lower and lower, according as the temperature rises, and the difference between the columns in A and B, corresponding to each temperature, will give the measure of the pressure of the vapour.

490. **Arago and Dulong's apparatus.** — The pressure of steam proceeding from water at temperatures above the boiling point was ascertained experimentally by Messrs. Arago and Dulong, and also by M. Regnault. The apparatus used by the former, consisted of two gun barrels, closed at their lower ends, and inserted steam-tight in a boiler; each of these barrels was filled with mercury, and contained a thermometer which showed the temperature, the one of the water, and the other of the steam in the boiler. To measure the pressure of the steam, a siphon gauge, such as that described in (262.) was used. In this way, the pressure of steam from one to twenty-four atmospheres, with its corresponding temperature, was ascertained.

491. **Regnault's apparatus.** — This is attended with the advantage of indicating all pressures and temperatures, whether above or below the boiling point. His process consists in boiling water in a vessel under a known pressure, and ascertaining the temperature at which it boils. This method depends upon the principle that when the water boils, the steam it produces will have a pressure precisely equal to that to which the water itself is submitted,— a principle which is familiar and well established. Thus, for example, the steam produced from water boiled under the ordinary pressure of the atmosphere of 15 lbs. per square inch, has, as is well known, that pressure.

The apparatus consists of a copper boiler (*fig.* 255.), closed so as to be steam-tight, filled to about a third of its capacity with water, and placed upon a charcoal furnace. The tubes of four thermometers, whose bulbs descend to different depths in it, pass steam-tight through collars in the top. Two of these bulbs are immersed in the upper, and two others in the lower strata of the liquid. The boiler C, is connected by a tube A B, with a large

glass globe M, having a capacity of about five gallons, which is filled with air. The tube A B is surrounded by a larger tube D, which is kept filled with cold water, flowing from a cistern E, and discharged into another A′. From the upper part of the globe M, two tubes proceed, one of which communicates with an air gauge O, and the other H, is terminated in a connecting piece H′ which may be attached at pleasure either to the plate of an air pump, or to that of a condenser, so that the air in M can be made to have

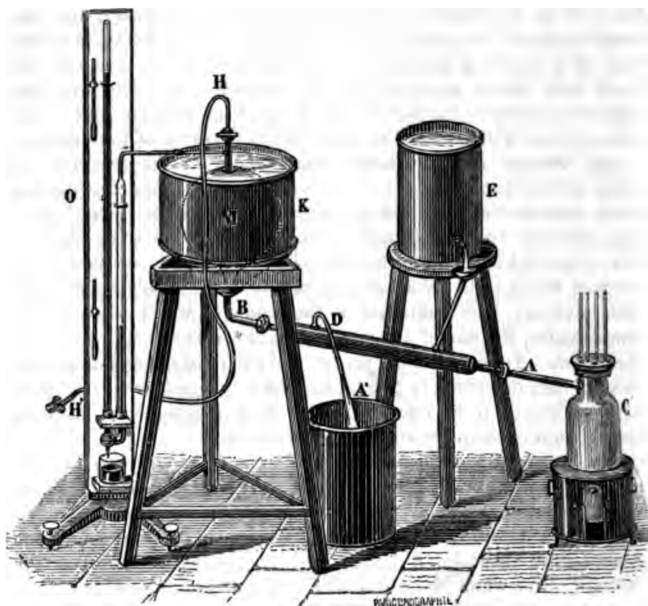


Fig. 255.

any degree of pressure, either above or below that of the atmosphere. The globe M is immersed in a reservoir of water at the temperature of the surrounding air.

If it be desired to measure the pressure of the vapour of water corresponding to temperatures below the boiling point, the connector H′ is attached to the plate of an air pump, and the air in M is gradually rarefied, so as to assume a series of decreasing pressures below that of the atmosphere. The thermometers in C show the temperatures corresponding to these pressures severally, and the gauge O shows the corresponding pressures.

If it be desired to ascertain the pressures corresponding to tem-

peratures above the boiling point, the connector H′ is attached to a condenser or a force pump, by means of which the air in M and in the boiler C, is submitted to a series of increasing pressures above that of the atmosphere. The corresponding temperatures, as before, at which the water boils in C, are indicated by the thermometers.

492. **Mechanical force developed in evaporation.** — When a liquid expands into vapour, it exerts a certain mechanical force, the amount of which depends on the pressure of the vapour, and the increased volume which the liquid undergoes in evaporation. Thus, if a cubic inch of a liquid swells by evaporation into 2000 cubic inches of vapour, having a pressure of 10 lbs. per square inch, it is easy to show that a mechanical force is developed in such evaporation which is equivalent to 20000 lbs. raised through one inch. For, if we imagine a cubic inch of the liquid confined in a tube, the bore of which measures a square inch, it will, when evaporated, fill 2000 inches of such tube, and, in swelling into that volume, will exert a pressure of 10 lbs., so that it would in fact raise a weight of 10 lbs. through that height. Now 10 lbs. raised through the height of 2000 inches, is equivalent to 20000 lbs. raised through the height of one inch.

Since, however, it is customary to express the mechanical effect by the number of pounds raised through one foot, the mechanical effect produced in the evaporation of each cubic inch of a liquid will be found by multiplying the number which expresses the volume of vapour produced by the unit of volume of the liquid by the number expressing the pressure of the vapour in pounds per square inch, and dividing the product by 12.

In the following tables, the relation between the temperature, pressure, density, volume, and mechanical effect of the vapour of water are given as determined by observation so far as the pressure of twenty-four atmospheres, and by analogy from that to the pressure of fifty atmospheres: —

Table I.

Showing the Pressure, Volume, and Density of the Vapour of Water produced at the Temperatures expressed in the first Column, as well as the Mechanical Effect developed in the Process of Evaporation.

Temperature Fahr.	Pressure.		Volume of Vapour containing Unit of Volume of Water.	Density of Vapour in Hundred Millionths of the Density of Water.	Mechanical Effect in Lbs. raised 1 Foot.	Temperature Fahr.	Pressure.		Volume of Vapour containing Unit of Volume of Water.	Density of Vapour in Hundred Millionths of the Density of Water.	Mechanical Effect in Lbs. raised 1 Foot.
	Inches of Mercury.	Lbs. per Square Inch.					Inches of Mercury.	Lbs. per Square Inch.			
[illegible]°	0·052	0·0255	650588	154	1383	35·6°	0·226	0·11	164332	609	1519
[illegible]	0·074	0·0363	470898	212	1423	37·4	0·241	0·12	154842	646	1525
[illegible]	0·104	0·05	342984	292	1451	39·2	0·257	0·13	145886	686	1531
[illegible]	0·144	0·07	251358	398	1480	41	0·274	0·13	137488	727	1536
[illegible]	0·199	0·10	182323	540	1483	42·8	0·291	0·14	129587	772	1542
[illegible]·8	0·212	0·10	174495	573	1514	44·6	0·310	0·15	122241	818	1549

TABLE I. — *continued.*

Temperature, Fahr.	Pressure. Inches of Mercury.	Pressure. Lbs. per Square Inch.	Volume of Vapour containing Unit of Volume of Water.	Density of Vapour in Hundred Millionths of the Density of Water	Mechanical Effect in Lbs. raised 1 Foot.
46·4°	0·330	0·16	115305	867	1555
48·2	0·351	0·17	108790	919	1559
50	0·373	0·18	102670	974	1565
51·8	0·397	0·19	99202	1032	1607
53·6	0·422	0·21	91564	1092	1577
55·4	0·448	0·22	86426	1157	1582
57·2	0·476	0·24	81686	1224	1588
59	0·505	0·25	77008	1299	1590
60·8	0·537	0·27	72913	1372	1598
62·6	0·570	0·28	68923	1451	1604
64·4	0·604	0·30	65201	1534	1610
66·2	0·641	0·32	61654	1622	1615
68	0·682	0·33	58224	1718	1621
69·8	0·721	0·35	55206	1811	1626
71·6	0·764	0·37	52260	1914	1632
73·4	0·810	0·40	49487	2021	1638
75·2	0·858	0·42	46877	2133	1644
77	0·909	0·45	44411	2252	1649
78·8	0·963	0·47	42084	2376	1655
80·6	1·019	0·50	39595	2507	1661
82·4	1·078	0·53	37838	2643	1667
84·2	1·143	0·56	35796	2794	1672
86	1·206	0·59	34041	2938	1678
87·8	1·276	0·63	32291	3097	1684
89·6	1·349	0·66	30650	3263	1689
91·4	1·425	0·70	29112	3435	1694
93·2	1·506	0·74	27636	3619	1700
95	1·591	0·78	26253	3809	1706
96·8	1·683	0·83	24897	4017	1712
98·6	1·773	0·87	23704	4219	1717
100·4	1·873	0·92	22513	4442	1722
102·2	1·974	0·97	21429	4666	1728
104	2·087	1·02	20343	4916	1734
105·8	2·196	1·08	19396	5156	1740
107·6	2·315	1·13	18469	5418	1746
109·4	2·439	1·20	17572	5691	1751
111·2	2·584	1·27	16805	6023	1774
113	2·707	1·33	15938	6274	1762
114·8	2·850	1·40	15185	6585	1768
116·6	3·000	1·47	14472	6910	1774
118·4	3·158	1·55	13809	7242	1781
120·2	3·322	1·63	13154	7602	1785
122	3·494	1·71	12546	7970	1791
123·8	3·673	1·80	11971	8354	1796
125·6	3·861	1·89	11424	8753	1802
127·4	4·058	1·99	10901	9174	1807
129·2	4·263	2·09	10410	9606	1813

Temperature, Fahr.	Pressure. Inches of Mercury.	Pressure. Lbs. per Square Inch.	Volume of Vapour containing Unit of Volume of Water.	Density of Vapour in Hundred Millionths of the Density of Water.	Mech cal Eff in L rais 1 Fo
131°	4·477	2·19	9946	10054	181
132·8	4·700	2·30	9501	10525	182
134·6	4·934	2·42	9082	11011	18
136·4	5·177	2·54	8680	11523	18
138·2	5·431	2·66	8303	12044	18
140	5·695	2·79	7937	12599	18
141·8	5·973	2·93	7594	13179	18
143·6	6·258	3·07	7267	13760	18
145·4	6·558	3·21	6957	14374	18
147·2	6·869	3·37	6662	15010	18
149	7·193	3·53	6382	15668	18
150·8	7·530	3·69	6114	16356	18
152·6	7·881	3·86	5860	17060	18
154·4	8·246	4·04	5619	17797	18
156·2	8·624	4·23	5386	18566	18
158	9·019	4·42	5167	19355	19
159·8	9·427	4·62	4957	20174	19
161·6	9·852	4·83	4759	21013	19
163·4	10·293	5·05	4569	21889	19
165·2	10·749	5·27	4387	22794	19
167	11·223	5·50	4204	23789	19
168·8	11·715	5·74	4048	24702	19
170·6	12·224	5·99	3891	25699	19
172·4	12·752	6·25	3741	26739	19
174·2	13·298	6·52	3599	27789	19
176	13·862	6·80	3462	28889	19
177·8	14·449	7·08	3331	30025	19
179·6	15·055	7·38	3206	31195	197
181·4	15·680	7·69	3087	32399	197
183·2	16·328	8·00	2973	33637	198
185	16·996	8·33	2864	34916	198
186·8	17·688	8·67	2760	36237	199
188·6	18·401	9·02	2660	37590	200
190·4	19·138	9·38	2565	38984	200
192·2	19·897	9·75	2474	40417	201
194	20·680	10·14	2387	41891	201
195·8	21·488	10·53	2304	43405	202
197·6	22·321	10·94	2224	44956	202
199·4	23·179	11·36	2148	46556	203
201·2	24·062	11·80	2075	48201	204
203	24·971	12·24	2005	49886	204
204·8	25·908	12·70	1938	51613	2051
206·6	26·874	13·17	1873	53388	205
208·4	27·860	13·66	1812	55191	206
210·2	28·877	14·16	1751	57055	2066
212	29·921	14·67	1696	58955	2073

TABLE II.

Showing the Temperature, Volume, and Density of Vapour of Water, corresponding to Pressures of from 1 to 50 Atmospheres.

From 1 to 24 Atmospheres obtained by Observation.

" 24 to 50 " " Analogy.

Pressure, Atmospheres.	Temperature, Fahrenheit.	Volume of Vapour produced by Unit of Volume of Water.	Density of Vapour (Density of Water = 1).	Pressure, Atmospheres.	Temperature, Fahrenheit.	Volume of Vapour produced by Unit of Volume of Water.	Density of Vapour (Density of Water = 1).
1	212	1696	0·0005895	2½	263·84	731·39	0·0013673
1½	233·96	1167·8	8563	3	275·18	619·19	16150
2	250·52	897·09	0·0011147	3½	285·08	537·96	18589

TABLE II. — *continued.*

Pressure, Atmospheres.	Temperature, Fahrenheit.	Volume of Vapour produced by Unit of Volume of Water.	Density of Vapour (Density of Water=1).	Pressure, Atmospheres.	Temperature, Fahrenheit.	Volume of Vapour produced by Unit of Volume of Water.	Density of Vapour (Density of Water=1).
4	293·72	476·26	0·0020997	16	398·48	135·90	0·007359
4½	300 38	427 18	23410	17	403·88	128·71	7769
5	307·58	388·16	25763	18	408·92	122·28	8178
5½	314·24	355·99	28091	19	413·78	116·51	8583
6	320·36	328·93	30402	20	418·46	111·28	8986
6½	326·30	305·98	32683	21	422 96	106·53	9387
7	331·70	286 12	34911	22	427·28	102·19	9785
7½	336·92	268·82	37217	23	431·42	98·21	0·010182
8	341·78	253 59	39434	24	435·56	94·56	10575
9	350·78	227·98	43865	25	439·34	91·17	10968
10	358·88	207·36	48226	30	457·16	77·50	12903
11	366·80	190·27	52557	35	472·64	68·20	14663
12	374·00	175 96	56834	40	486·50	60·08	16644
13	380·66	163·74	6107	45	499 10	54·06	18497
14	386·96	153·10	6527	50	510·62	49·31	20306
15	392·90	144·00	6944				

493. **Specific gravities of vapour.** — These, like those of gases, are usually referred to air as a standard, the air being supposed to have the standard temperature of 32°, the barometer standing at 30 inches. The density of vapours, however, is a term frequently used to express the ratio of a given volume of the vapour to an equal volume of air, having the same temperature and pressure.

It has been ascertained experimentally that in the case of steam, at all temperatures above 250°, this ratio is invariable, the steam being supposed to be saturated.

494. **Gay Lussac's apparatus.** — The apparatus by which the density of vapour, in this sense of the term, was ascertained by Gay Lussac, is represented in *fig.* 256. A graduated glass tube B of large diameter is filled with mercury, and, being inverted in the usual manner, is plunged in a cistern of mercury. The mercury will be sustained in the tube B by the atmospheric pressure. A small and thin bulb of glass A is filled through an opening in a small tube projecting from it, with the liquid whose vapour is to be examined, and hermetically sealed. This ball is let into the mouth of the tube B, and ascends to the top through the mercury by its comparative levity. The tube B is then surrounded by a glass cylinder C, open at both ends, the lower end being immersed in the mercury; this cylinder is then filled with water or oil to a level above the top of the tube B, and a thermometer D is immersed in it.

The furnace upon which the cistern is placed being then lighted, the mercury in the tube B is heated. The bulb A will then soon burst by reason of the expansion of the liquid it contains, and the liquid once liberated will begin to produce vapour, the pressure

of which will cause the mercury in the tube B to descend. The thermometer D will then indicate the temperature of the vapour in B, and the difference between the height of the mercury in B and that of the barometer will indicate its pressure.

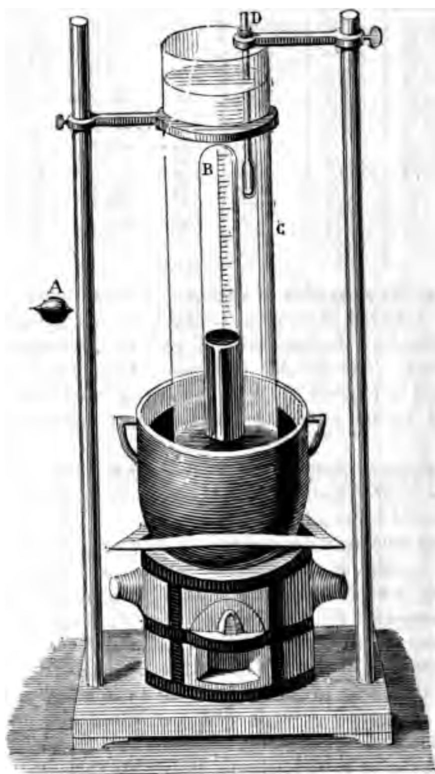


Fig. 256.

The weight of the vapour being known by knowing that of the liquid which was contained in the bulb A, its density, at each temperature which it assumes, can be determined and can be compared with that of air at the same temperature.

It is found that the ratio of these densities is constant for the vapour of most liquids at all temperatures which are above their boiling points.

The following are those ratios for the undermentioned vapours:—

Air	10000	Vapour of sulphuret of carbon	26447
Vapour of water	6235	„ essence of turpentine	50130
„ alcohol	16138	„ mercury	6976
„ sulphuric ether	25860	„ iodine	8716

495. **Mixture of gases and vapours.** — When a gas and vapour which have no mutual chemical action are inclosed in the same space, they will exercise separately on the confining surfaces precisely the same pressures which each would produce if it occupied the same space in the absence of the other, and consequently, the total pressure which their mixture will produce will be equal to the sum of the pressures which they would produce separately.

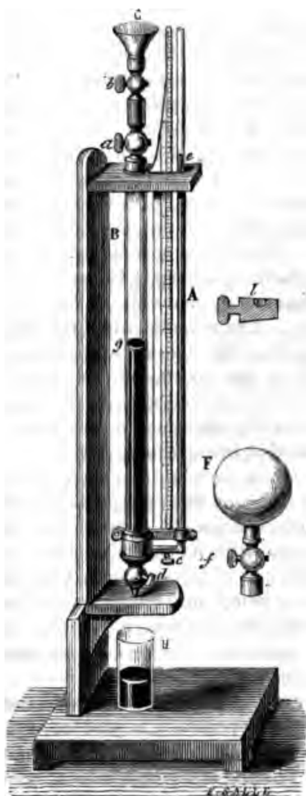


Fig. 257.

The apparatus by which Gay Lussac established experimentally this important law, is shown in *fig.* 257., and consists of a glass tube B, of large bore, having iron caps furnished with stop-cocks, *a*, *d*, cemented on to the top and bottom. It communicates by a horizontal branch, having a stop-cock *c*, with another vertical tube A, of much smaller bore and greater height. A graduated scale is placed between these tubes so as to indicate the height of the column in each of them.

The stop-cock *d* being closed and *a* and *c* opened, let mercury be poured into the tube B until it rises to the level of the stop-cock *a*. Since there is free communication between the two tubes, the mercury will rise to the same height in the lesser tube A.

Let C be a funnel, having a stop-cock *b*, which can be screwed upon the tube proceeding from the stop-cock *a*.

The stop-cock *b* is constructed in a peculiar manner. Instead of being pierced as usual, by a hole passing quite through it, the hole passes only half through it, so that in no position can it open a free communication between the funnel c and the tube B.

A bulb F is provided, furnished with a stop cock *f*, in which dry air or gas can be condensed, and which also can be screwed upon the neck of the stop-cock *a*.

Now, let us suppose dry air or gas to be condensed in the bulb F, the stop-cock *f* being closed. Let the funnel c be unscrewed from the neck of the stop-cock *a*, the mercury being still at the level of the stop-cock *a* in both tubes. Let the bulb F be now screwed on, and let the stop-cock *f* be opened so that the column of mercury in B shall be subject to the pressure of the condensed air or gas in the bulb, while the column in the tube A is subject to the lesser pressure of the atmosphere. The column of mercury, therefore, in the tube B will descend, and the column in A will rise until the difference of their heights represents the excess of the pressure of the gas above the mercury in B over that of the atmosphere. Let the cock *a* be now closed, and let the cock *d* be opened, so that a portion of the mercury in the tubes shall fall into the cistern H. The space occupied by the air or gas in the tube B being thus gradually enlarged, the pressure of the gas will be proportionally diminished, and will at length be reduced to that of the atmosphere. The moment when this takes place will be known by observing when the column of mercury in the tube A falls to the exact level of the column in the tube B. When this takes place let the cock *d* be closed; we shall then have a portion of dry air or gas above the mercury in the tube B, having a pressure exactly equal to that of the atmosphere.

The bulb F being removed from the neck of the stop-cock *a*, let the funnel c be screwed on in its place, and let a portion of the liquid whose vapour is under observation be poured into the funnel. If the stop-cock *b* be turned with its cavity upwards, the cavity will be filled with the liquid, and if the stop-cock *b* be then turned half round, the stop-cock *a* being previously opened, the drop of liquid in the cavity will fall into the tube B, where it will float upon the mercury; and by repeating this process, as many drops as may be desired can be thus let in.

When a portion of the liquid has thus been let in upon the mercury and is enclosed by shutting the stop-cock *a*, a part of it will evaporate, and the vapour will be mixed with the air in the tube B; and at the same time the column of mercury in the tube A, which was at the level of the mercury in B, will rise above it, and will continue to rise until the space in the tube B has been saturated with vapour.

Now, if the difference between the heights of the columns in the two tubes be observed, it will be found to be exactly equal to the height of a column which would balance the pressure of the vapour of the liquid, which would saturate the space in the tube B, if no air or gas were present there.

It follows, therefore, from this, that the presence of the air or gas with which the vapour is mixed does not in any respect change or modify the effect produced by the pressure of the vapour.

This experiment may be varied by varying the temperature to which the tube B is exposed. It will be found in all cases that the difference between the columns of mercury in the two tubes represents exactly the pressure of the vapour, which would saturate the space in the tube B, at the temperature to which it is exposed.

496. **Liquids having different temperatures communicating in closed vessels.** — If a closed vessel in which a liquid is raised to an elevated temperature, communicate with another vessel which is maintained at a lower temperature, the vapour evolved by the liquid at the higher temperature, will nevertheless have the pressure corresponding to the lower temperature. This is easily ascertained experimentally, by applying any pressure gauge to the vessel in which the liquid is maintained at the higher temperature. This fact is easily explained by the partial condensation which the vapour constantly suffers in the colder vessel.

497. **Spheroidal state of liquids.** — If a small drop of water, or certain other liquids, be let fall from a funnel, terminating in a small and fine tube, upon a surface of metal rendered red hot, the following remarkable phenomena will be manifested: —

1°. The liquid will not wet the surface, but will appear to avoid touching it, and will assume a globular form like that which water affects when it is diffused upon a greasy surface, or like globules of mercury upon glass.

2°. Instead of entering into violent ebullition, as might be expected, the temperature of the liquid will be very little affected, and the drop of liquid will either remain at rest or be affected with gyratory motion.

3°. When the surface on which it rests is cooled down to the temperature of 400° or 500°, the liquid will begin to diffuse itself on the surface, and will be suddenly scattered with violence in all directions.

These experiments can be most conveniently made with a shallow capsule of metal shaped like a watch glass, and which may be rendered white hot by a powerful lamp. The liquid may be let fall upon it in small drops by a fine pointed syringe or funnel.

498. M. Boutigny, who has made numerous experiments on these phenomena, appears to have demonstrated that in such cases

the globule of liquid is not in contact with the incandescent metal, but, on the contrary, is separated from it by a space of sensible magnitude. He affirms that, directing his eye between the globule and the red hot surface, he has seen distinctly in the intervening space objects on the other side of the globule. This phenomenon has not yet been clearly and satisfactorily explained; but it is generally supposed that around the globule an atmosphere of vapour is formed, which has sufficient elasticity to prevent the contact of the globule with the metal. The liquid composing the drop, being thus prevented from contact with the metal, receives no heat from it, except that which comes by radiation; and being more or less diathermanous, the chief part of this passes through it without affecting its temperature.

To the same class of phenomena belongs an effect with which every one who has frequented forges or iron works is familiar. If a bar of iron or steel, rendered white hot, be plunged suddenly in water it will continue for some moments without perceptibly affecting or being affected by the water; it will retain its incandescence, and will produce neither hissing nor effervescence. It is only when its temperature has been lowered that these effects will be manifested.

Among the experiments of M. Boutigny is one which is so striking in its result as to merit a special notice. A capsule of platinum being rendered white hot, a small quantity of anhydrous sulphurous acid in the liquid state is poured upon it.

The boiling point of this liquid being so low as 14° Fahr., its temperature in the liquid state is necessarily much lower; and as it continues in the liquid state upon the white hot metal, the two bodies are thus exhibited nearly in contact, one having the temperature of 800° or 900°, and the other under 14°. A few drops of water are then let fall upon the liquid acid, and, notwithstanding their proximity to the white hot metal, they are instantly congealed.

499. **Vapour separated from a liquid may be dilated by heat like any gaseous body.** — In the tables given in (492.) the vapour is considered as being in the state of the greatest density which is compatible with its temperature. It must be remembered that vapour separated from the liquid may, by receiving heat from any external source, be raised like so much air, or other gaseous fluid, to any temperature whatever, and that the elevation of its temperature under such circumstances is attended with the same effects as atmospheric air. If it be so confined as to be incapable of expansion, its pressure will be augmented a $\frac{1}{480}$th part by each degree of temperature it receives; and if it be capable of expanding under an uniform pressure, then its volume will be augmented in the same ratio.

500. Vapour which receives a supply of heat after it has been separated from the liquid, and which may therefore be denominated *superheated vapour*, has some important properties which distinguish it from the vapour which proceeds directly from the liquid.

The vapour which proceeds directly from a liquid by the process of evaporation, contains no more heat than is essential to its maintenance in the vaporous form. If it lose any portion of this heat, a part of it will become liquid; and the more it loses, the more will return to the liquid state, until, being deprived of all the heat which it had received in the process of evaporation, the whole of the vapour will become liquid.

But, in the case of superheated vapour, the effects are different. Such vapour may lose a part of its heat, and still continue to be vapour. In fact, no part of it can be reduced to the liquid state until it lose all the heat which had been imparted to it after evaporation.

501. It is sometimes affirmed that vapour may, by mere mechanical compression, be reduced to the liquid state. This is an error. It is true neither in relation to vapour raised directly from liquids, nor of superheated vapour.

502. If vapour raised directly from a liquid, at any proposed pressure, be, after separation from the liquid, either compressed into a diminished volume or allowed to expand into an increased volume, its temperature will be raised in the one case and lowered in the other; and, at the same time, its pressure will be augmented by the diminution and diminished by the augmentation of volume. It will be found, however, that the temperature, pressure, and volume will in every case be exactly those which the vapour would have had if it had been directly raised from the liquid at that temperature and pressure.

Thus, the vapour raised from water at the temperature of 68° has a volume 58224 times greater than the water that produced it (see Table I. p. 324.). Now let this vapour, being separated from the water, be compressed until it be reduced to a volume which is only 1696 times that of the water which produced it, and its temperature will rise to 212°, exactly that which it would have had if it had been directly raised from the water under the increased pressure to which it has been subjected.

In the same manner, whatever other pressure the vapour may be submitted to, it will still, after compression, continue to be vapour, and will be identical in temperature and volume with the vapour which would be raised from the same liquid directly if evaporated under the increased pressure.

503. Although mere compression cannot reduce any part of a volume of vapour to the liquid state, it will facilitate such a change

by raising the temperature of the vapour without augmenting the quantity of heat it contains, and thereby rendering it possible to abstract heat from it. Thus, for example, if a volume of vapour at the temperature of 32° be given, it may be difficult to convert any portion of it into a liquid, because heat cannot be easily abstracted from that which has already a temperature so low. But if this vapour, by compression, and without receiving any accession of heat, be raised to the temperature of 212°, it can easily be deprived of a part of its heat by placing it in contact with any conducting body at a lower temperature; and the moment it loses any part of its heat, however small, a portion of it will be reduced to the liquid state.

504. **Permanent gases are superheated vapours.** — It may be considered as certain that all that class of bodies which are denominated permanent gases are the superheated vapours of bodies which, under other thermal conditions, would be found in the liquid or solid state. It is easy to conceive a thermal condition of the globe, which would render it impossible that water should exist save in the state of vapour. This would be the case, for example, if the temperature of the atmosphere were 212° with its present pressure. A lower temperature, with the same pressure, would convert alcohol and ether into permanent gases.

505. **Processes by which gases have been liquefied and solidified.** — The numerous experiments by which many of the gases hitherto regarded as permanent have been condensed and reduced to the liquid, and, in some cases, to the solid state, have further confirmed the inferences based on these physical analogies. The principle on which these experiments have in general been founded is, that if, by any means, the heat which a superheated vapour has received after having assumed the form of vapour can be taken from it, the condensation of a part of it must necessarily attend any further loss of heat, since, by what has been explained, it will be apparent that no heat will remain in it except what is essential to its maintenance in the vaporous state.

The gas which it is desired to condense is first submitted to severe compression, by which its temperature is raised either by diminishing its specific heat or by developing heat that was previously latent in it. The compressed gas is at the same time surrounded by some medium of the most extreme cold; so, that, as fast as heat is developed by compression, it is absorbed by the surrounding medium.

When, by such means, all the heat by which the gas has been surcharged has been abstracted, and when no heat remains save what is essential to the maintenance of the elastic state, the gas is in a thermal condition analogous to that of vapour which has been

directly raised by heat from a liquid, and which has not received any further supply of heat from any other source. It follows, therefore, that any further abstraction of heat must cause the condensation of a corresponding portion of the gas.

506. The following gases, being kept at the constant temperature of 32° by depriving them of heat as fast as their temperature was raised by compression, have been reduced to the liquid state. The pressures necessary to accomplish this are here indicated: —

Names of Gases condensed.	Pressure under which Condensation took place.
	Atmospheres.
Sulphurous acid - - -	1·5
Cyanogen gas - - - -	2·3
Hydriodic acid - - -	4·0
Ammoniacal gas - - -	4·4
Hydrochloric acid - - -	8·0
Protoxide of azote - - -	37·0
Carbonic acid - - - -	39·0

If these substances be regarded as liquids, the above pressures would be those under which they would vaporise at 32°. If they be regarded as vapours, they are the pressures under which they would be condensed at 32°.

M. Pouillet succeeded in condensing some of these gases at the following higher temperatures and greater pressures: —

Gas.	Temperature, Fahrenheit.	Pressure, Atmospheres.
Sulphurous acid - - -	46°·4	2·5
Ammoniacal gas - - -	50	5
Protoxide of azote - - -	51·8	43
Carbonic acid - - -	50	45

Hydrochloric acid has been liquefied under a pressure of 40 atmospheres, at the temperature of 50°.

507. **Experiments of M. Pouillet.** — The apparatus used in these experiments consisted of two glass tubes A B (*fig.* 258.) of small and perfectly uniform calibre, each 80 inches long. Their lower ends were inserted in a block of cast iron, D, communicating by a horizontal tube C, with a massive cast iron reservoir *c*, the lower part of which is filled with mercury, and the upper part with oil. A solid plunger *d* passes through an oil-tight collar and stuffing-box *e*, and is urged by a screw E, turned by a powerful handle F. When the screw is turned, so as to cause the plunger *d* to descend into the reservoir, the oil which it displaces forces an equal volume of mercury from the reservoir into the tubes A B.

The diameters of the tubes A B were about the 10th of an inch. The gases operated upon, being previously obtained perfectly dry

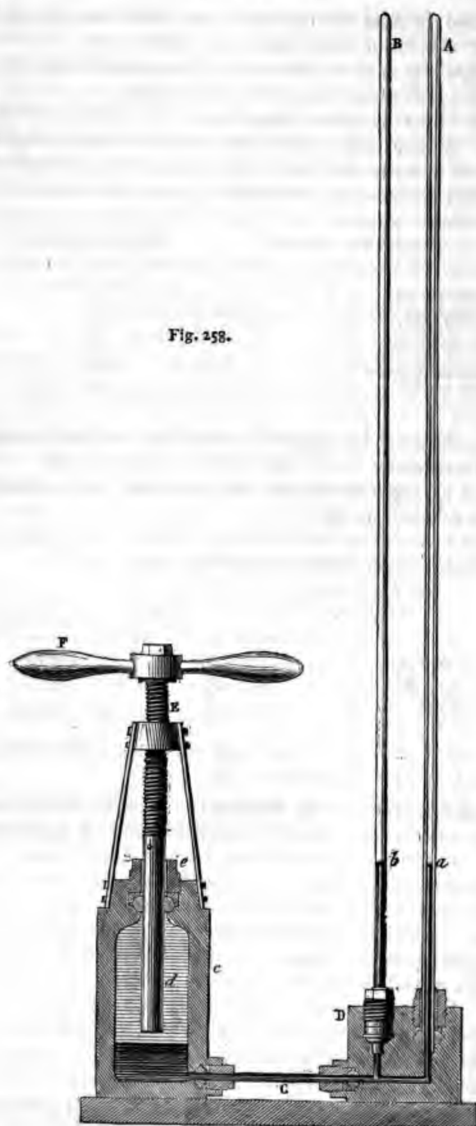


Fig. 258.

and pure, are introduced into the tubes at the top; and when filled with them, the tops are closed by the blowpipe.

By this apparatus M. Pouillet was able to obtain a compressing force of the prodigious intensity of 100 atmospheres, which is equivalent to 1500 lbs. per square inch.

The liquids produced by the compression of carbonic acid and the protoxide of azote, were perfectly limpid and colourless. That produced by ammoniacal gas had a yellowish green colour.

508. **Carbonic acid.** — Of all the gases which have been liquefied, that which presents circumstances of the greatest interest is carbonic acid. We shall, therefore, here briefly describe this gas, and show the process by which it has been reduced, not merely to the liquid, but even to the solid state.

Carbonic acid is a colourless aeriform fluid, nearly without odour, and having a slightly acid flavour. Bulk for bulk, it is heavier than air in the proportion of nearly 3 to 2; and this relative weight is such, that if the surrounding air be not agitated, the gas may be poured from one vessel, A, *fig.* 259., to another vessel, B, as a liquid would be.

There are various methods of producing this gas, one of which consists in putting pieces of marble in a flask, A, *fig.* 260. The

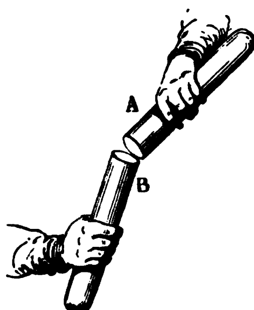


Fig. 259.

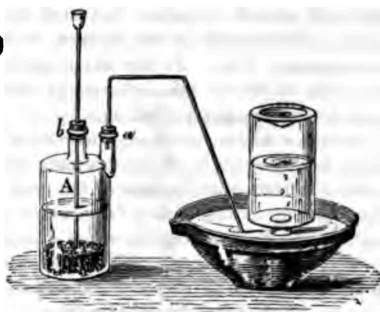


Fig. 260.

flask is then half filled with water; a glass tube terminating with a funnel above, passes, air-tight, through its neck, *b*, the lower end descending below the level of the water. Another rectangular glass tube is inserted, air-tight, in a second neck, *a*, the other end of which is bent down below the surface of the water in an adjacent vessel, in which a flask, previously filled with water, is inverted, the end of the tube, turned upwards, entering the mouth of this flask. At the commencement of the process, the atmospheric pressure

acting on the surface of the water in the vessel, prevents the water from falling out of the flask, and keeps it filled.

A small quantity of sulphuric acid is now poured into the vessel A through the tube which passes through the neck *b*; this, mixing immediately with the water, forms a solution which produces a strong chemical action on the marble. Marble being a substance whose constituents are carbonic acid and lime, and the sulphuric acid having a much stronger attraction than the carbonic acid for the lime, tears the latter from it, liberating the carbonic acid, which rises in the gaseous state to the upper part of the flask, A, passes through the neck *a*, then through the bent tube, and, rising in bubbles through the water in the inverted flask, collects in the upper part of it, pressing the water downwards, as shown in the figure.

509. This gas has so strong an affinity for water, that it mixes intimately with it, so that under the ordinary pressure of the atmosphere, water in contact with carbonic acid will absorb its own bulk of that gas; but what is more remarkable, it will still absorb its own bulk to whatever extent the density of the gas may be increased. Thus, if a gallon of water be in contact with carbonic acid, under the atmospheric pressure, it will absorb a gallon of that gas. If the pressure be two atmospheres, it will still absorb a gallon, but that gallon will contain twice as much carbonic acid as the former, in consequence of the double compressing force. In the same manner, if it be subject to the pressure of three atmospheres, it will absorb three times the quantity of the gas, and so on.

If water which has thus absorbed a large quantity of carbonic acid, in consequence of the pressure exerted upon it, be suddenly relieved from that pressure, the gas previously absorbed will immediately escape, rising from every part of the water in small bubbles, and producing the effect denominated *effervescence*.

This is exactly what takes place when a bottle of champagne is uncorked: so long as the cork maintained the pressure, the gas previously absorbed by the liquid was retained; but the moment the removal of the cork relieves the liquid from this pressure, the gas rises, and produces the sparkling effervescence with which every one is familiar.

The same observations are applicable to all fermented liquors and gaseous drinks, such as soda water, effervescent lemonade, and so on.

510. **Effervescent drinks.** — A simple apparatus by which gaseous water can be made is now a common object of sale in the shops. This consists of a stone bottle, shown in *fig.* 261., a vertical section of it being given in *fig.* 262. The bottle is divided into

two compartments, A and B, between which there is a communication by a capillary canal *a b*; the substance which generates the



Fig. 261.



Fig. 262.

gas is introduced through an opening *o* into an acid solution contained in A, after which the opening *o* is closed by a screw cover provided for the purpose. The upper compartment B of the bottle is previously filled with water to the point *a*; a pipe *i* descends in it nearly to the bottom, and communicates with a lateral spout *v*; that communication, however, being cut off when the screw *p* is turned, so that its end presses on the upper opening of the tube *i*. When the screw *p* is turned down, so as to shut off the communication between *i* and *v*, the carbonic acid generated in A rising through *b a*, collects in the upper part of the bottle; and being pressed upon the surface of the water, enters into combination with it, and this goes on until the pressure of the gas becomes so great as to retard or stop its generation in A. In all states of the gas the water B will contain as much of it as would occupy the space filled by the water if the water were absent.

When it is desired to obtain a draught of the liquid, a glass is held to the mouth of the tube *v* and the screw *p* is turned so as to open the communication between *i* and *v*, when immediately the pressure of the gas in the bottle forces the water up the tube *i*, and through *v* into the glass. When the glass is filled, the screw *p* is closed, and the water in the glass being relieved from the excessive pressure to which it was subject in the bottle, the gas effervesces, and an effect is produced with which every one is familiar.

511. **Thirolier's apparatus.** — The liquefaction and solidification of carbonic acid gas was first effected by M. Thirolier, by

means of an apparatus, a vertical section of which is represented in *fig.* 263., where A and B are two strong metal cylinders, con-

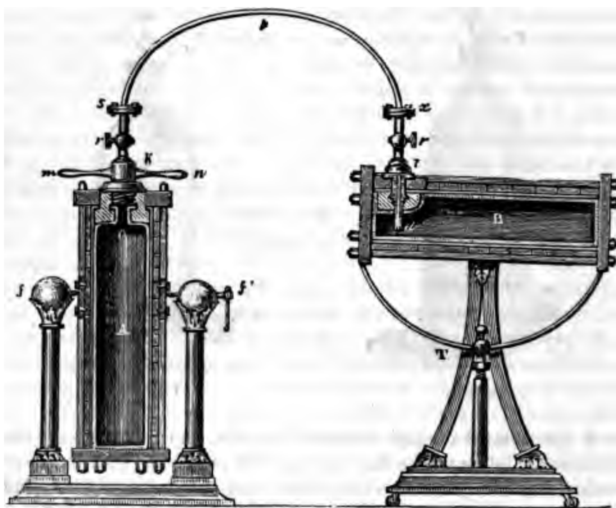


Fig. 263.

structed so as to resist an enormous pressure: they are closed by screw stoppers, and communicate with each other by a small pipe *s t x*; stop-cocks are placed at *r* and *r'*, so as to open or close at pleasure the communication between the pipe *s t x* and either cylinder. The cylinder A is called the *generator*, and B the *receiver*.

These cylinders are constructed precisely alike, each containing about 2 gallons. The generator is suspended vertically between two points, *f* and *f'*, placed a little above its centre of gravity, on which it is capable of receiving a rocking motion. Removing the stopper K from the generator, a gallon of water is introduced into it at the temperature of 100°, with about 4 lbs. of bicarbonate of soda. A cylindrical copper tube *u v* (*fig.* 264.), containing about 2 lbs. of concentrated sulphuric acid, is then introduced into the generator, and so placed as to be held always in the direction of its axis, so that when the generator is vertical, no part of the acid can fall from the tube. By turning the generator upon its supports until it is inclined a little beyond a horizontal position, the acid is all discharged from the tube, and mixes with the solution of the bicarbonate.



Fig. 264.

The top of the generator being previously closed by the handles *m n* and the stop-cock *r*, chemical action commences, and the sulphuric acid, attracting the soda from the bicarbonate, liberates the carbonic acid, its other constituent, with which the upper part of the generator becomes immediately filled, and its condensation soon becomes so great as to exercise a pressure by which a part of the gas is liquefied in the generator. The tube *s t x* being now screwed on, and the stop-cocks *r* and *r'* opened, the carbonic acid rushes in the gaseous state through the tube into the receiver B, where it is soon condensed, and assumes the liquid form. This condensation is produced partly by the pressure of the gas, and partly by the difference between the temperatures of the generator and receiver. By the action of the sulphuric acid on the water with which it is mixed the temperature of the solution and of the generator rises to about 90°, while the temperature of the receiver is not greater than that of the surrounding air. The pressure of the carbonic acid corresponding to the former temperature being 75 atmospheres, while that corresponding to the latter is only 50 atmospheres, a condensation must take place sufficient to reduce the density of the gas in the proportion of 3 to 2; so that in less than a minute all the carbonic acid of the generator is transferred to the receiver, after which the communications are closed, the generator refilled, and the process repeated. After this operation has been performed five or six times, about half a gallon of liquid carbonic acid will be collected in the receiver. Above the surface of this liquid is a gaseous atmosphere, exercising a pressure of about 50 atmospheres, supposing the temperature of the surrounding medium to be about 60°. It is evident that if the stop-cock *r'* be opened, the tube *a* being below the level of the liquid, the liquid acid will be projected with great force from the receiver. If the tube *s t x* were detached, and the liquid were allowed to issue into the air, it would immediately take the gaseous form, producing a whitish cloud, like steam issuing from the valve of a high-pressure engine. Owing to the enormous quantity of heat rendered suddenly latent by the instantaneous conversion of the liquid acid into gas, the gas thus issuing would have an extremely low temperature. If, however, the jet of liquid acid be directed into a strong metallic flask, a portion of it only will be volatilised, taking from the sides of the flask the heat which it renders latent. By this means the temperature of the flask will be reduced to a temperature so low as —94°, or 94° below zero. The acid reduced to this temperature will become solid, under the form of a white cotton, like snow. It can be preserved in this much longer than in the liquid state; its evaporation being very slow, owing to its low conducting power

in the solid form. An air thermometer surrounded with it would show a temperature of $-108°$, or 108° below zero, or 140° below the freezing point.

A flake of this snowy substance can be placed upon the hand without producing any considerable sense of cold, because it is continually isolated from the hand, and the contact is prevented by a stratum of gas which is continually disengaged from it,—an effect which has an obvious analogy to the phenomena manifested by liquids let fall upon red hot iron, as already described. If, however, instead of laying the acid flakes upon the hand, they are pressed between the fingers, a most painful sensation would be produced, like that attending a severe burn, and the skin will be blistered in the same manner.

The metallic box or flask in which the solid acid is usually collected is represented in *fig.* 265. It is composed of two parts *a b c d*, and *a′ b′ c′ d′* (*fig.* 266.), which can be easily united or

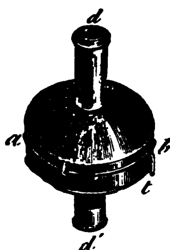




Fig. 265.

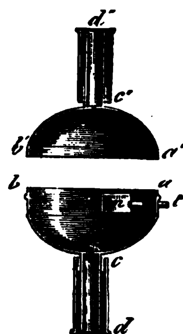


Fig. 266.

separated. The part *a b c d* has a tube *c d* leading to it, into which a small tube *u* enters, which has been previously fixed at *x* upon the receiver B, *fig.* 263. On opening the stop-cock *r′*, the liquid gas rushes out through *u*, and, passing through the tube *d c*, penetrates into the box, where it is discharged tangentially from the point of the tube *u*, which is bent at right angles to *d c*. It strikes against a plate of metal *m*, so disposed as to produce a gyratory motion; a part of the liquid acid takes the form of gas, which, after whirling round the box, escapes at the central tubes *c d* and *c′ d′*; the remainder of the acid is solidified in the form already described of snowy flakes, and can be collected on opening the box. The tubes *c d* and *c′ d′* are enveloped by two concen-

trical tubes wrapped with cloth, so that the operator can hold them without suffering from the severe cold of the remainder of the box.

If a liquid which does not combine chemically with the carbonic acid, and which is not congealed at a very low temperature be poured upon it, the evaporation of the acid is accelerated, because the liquid filling its pores increases considerably its conducting power.

The rapid evaporation thus effected produces a cold of extraordinary intensity, by means of which bodies immersed in the acid may be reduced to a temperature far below that of the solid acid. If such a mixture be placed under the receiver of an air pump, and the evaporation be further accelerated by making a vacuum around it, a temperature may be obtained which will be 180° below the freezing point.

The liquid commonly used for this purpose is ether. By means of the frigorific paste thus produced 2 lbs. of mercury may be easily solidified in a few minutes; and if a glass tube, hermetically sealed, containing liquid carbonic acid, be plunged in such a mixture, the acid will be immediately congealed, assuming the appearance of ice.

A most convenient apparatus for the liquefaction and solidification of carbonic acid on a large scale, has been recently constructed by Messrs. Deleuil, of Paris. This apparatus is represented in *fig.* 267. It consists of two cylinders, perfectly equal and similar, and similarly suspended. They are in cast iron, about 1¼ inch thick, and having a capacity of something less than a gallon. They are strongly bound with four longitudinal ribs and three hoops of wrought iron. The arrangement of stopcocks and other communications corresponds with that already described.

512. It has been found that when the gases are submitted to extreme compression, and deprived of a large portion of the surcharged heat, they begin to depart from the general law in virtue of which the density of gaseous bodies at the same temperature is proportional to the compressing force, and they are found to acquire a density greater than that which they would have under this general law. This would appear, therefore, as a departure from the law, preliminary to the final change from the gaseous to the liquid state; and in this point of view, analogies have been observed which render it probable that the point of condensation of several of the gases not yet liquefied has been very nearly approached.

Thus, it has been found that the density of several of them, among which may be mentioned light carburetted hydrogen and

olefiant gas (heavy carburetted hydrogen), has been sensibly greater than that due to the compressing force under extreme degrees of compression.

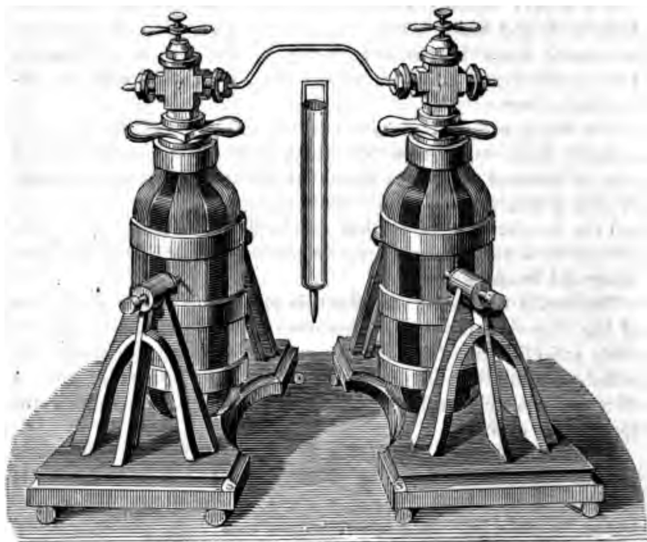


Fig. 267.

513. **Ebullition.** — If heat be continually imparted to a liquid, its temperature will be augmented, but will only rise to a certain point on the thermometric scale. At that point it will remain stationary, until the whole of the liquid shall be converted into vapour. During this process, vapour will be formed in greater or less quantity throughout the entire volume of the liquid, but more abundantly at those parts to which the heat is applied. Thus if, as usually happens, the heat be applied at the bottom of the vessel containing the liquid, the vapour will be formed there in large bubbles, and will rise to the surface, producing that agitation of the liquid which has been called *boiling* or *ebullition*.

This limiting temperature is called the *boiling point* of the liquid.

Different liquids boil at different temperatures. The *boiling point* of a liquid is therefore one of its specific characters.

514. Liquids in general being boiled in open vessels, are subject to the pressure of the atmosphere. If this pressure vary, as it

does at different times and places, or if it be increased or diminished by artificial means, the boiling point will undergo a corresponding change. It will rise on the thermometric scale as the pressure to which the liquid is subject is increased, and will fall as that pressure is diminished.

The boiling point of water is 212°, when subject to a pressure expressed by a column of 30 inches of mercury. It is 185°, when subject to a pressure expressed by 17 inches of mercury.

In general, the temperatures at which water would boil under the pressures expressed in the second column of the table (492.) are expressed in the first column.

515. Let water at the temperature of 200°, for example, be placed in a glass vessel, under the receiver of an air pump, and let the air be gradually withdrawn. After a few strokes of the pump the water will boil; and if the gauge of the pump be observed, it will be found that its altitude will be about 23½ inches. Thus, the pressure to which the water is submitted has been reduced from the ordinary pressure of the atmosphere, to a diminished pressure expressed by 23½ inches, and we find that the temperature at which the water boils has been lowered from 212° to 200°. Let the same experiment be repeated with water at the temperature of 180°, and it will be found that a further rarefaction of the air is necessary, but the water will at length boil. If the gauge of the pump be now observed, it will be found to stand at 15 inches, showing that at the temperature of 180° water will boil under half the ordinary pressure of the atmosphere. This experiment may be varied and repeated, and it will always be found that water will boil at that temperature which corresponds to the pressure given in the tables already referred to.

516. It is well known, that as we ascend in the atmosphere, the pressure is diminished in consequence of the quantity of air we leave below us, and that, consequently, the barometer falls. It follows, therefore, that at stations at different heights in the atmosphere, water will boil at different temperatures; and that the boiling point at any given place must therefore depend on the elevation of that place above the surface of the sea. Hence the boiling point of water becomes an indication of the height of the station, or, in other words, an indication of the atmospheric pressure, and thus the thermometer serves in some degree the purposes of a barometer.

517. In the following table the various temperatures are shown at which water boils in the different places therein indicated: —

Table of the boiling Points of Water at different Elevations above the Level of the Sea.

Names of Places.	Above Level of Sea.	Mean Height of Barometer.	Thermometer.
	Feet.	*Inches.*	*Degrees.*
Farm of Antisana	13455	17·87	187·3
Town of Micuipampa (Peru)	11870	19·02	190·2
Quito	9541	20·75	194·2
Town of Caxamarca (Peru)	9384	20·91	194·5
Santa Fé de Bogota	8731	21·42	195·6
Cuença (Quito)	8639	21·50	195·8
Mexico	7471	22·52	198·1
Hospice of St. Gothard	6808	23·07	199·2
St. Veran (Maritime Alps)	6693	23·15	199·4
Breuil (Valley of Mont Cervin)	6585	23·27	199·6
Maurin (Lower Alps)	6240	23·58	200·3
St. Rémi	5265	24·45	202·1
Heas (Pyrenees)	4807	24·88	202·8
Gavanne (Pyrenees)	4738	24·96	203·0
Briançon	4285	25·39	203·9
Baréges (Pyrenees)	4164	25·51	204·1
Palace of San Ildefonso (Spain)	3790	25·87	204·8
Baths of Mont d'Or (Auvergne)	3412	26·26	205·7
Pontarlier	2717	26·97	206·8
Madrid	1995	27·72	208·0
Innspruck	1857	27·87	208·4
Munich	1765	27·95	208·6
Lausanne	1663	28·08	208·9
Augsburg	1558	28·19	209·1
Salzburg	1483	28·27	209·1
Neufchâtel	1437	28·31	209·3
Plombières	1381	28·39	209·3
Clermont-Ferrand (Préfecture)	1348	28·43	209·3
Geneva and Friburg	1221	28·54	209·5
Ulm	1211	28·58	209·7
Ratisbon	1188	28·58	209·7
Moscow	984	28·82	210·2
Gotha	935	28·86	210·2
Turin	755	29·06	210·4
Dijon	712	29·14	210·6
Prague	587	29·25	210·7
Mâcon (Saône)	551	29·29	210·9
Lyons (Rhone)	532	29·33	210·9
Cassel	518	29·33	210·9
Göttingen	440	29·41	211·1
Vienna (Danube)	436	29·41	211·1
Milan (Botanic Garden)	420	29·45	211·1
Bologna	397	29·49	211·1
Parma	305	29·57	211·3
Dresden	295	29·61	211·3
Paris (Royal Observatory, first floor)	213	29·69	211·5
Rome (Capitol)	151	29·76	211·6
Berlin	131	29·76	211·6

518. **Latent heat of vapour.** — When a liquid is converted into vapour, a certain quantity of heat is absorbed and rendered latent in the vapour. The vapour which proceeds from the liquid has the same temperature as the liquid. It can be shown, however, experimentally, that, weight for weight, it contains much more heat. To render this manifest, let B (*fig.* 268.) be a vessel containing water, which is kept in the state of ebullition and at the temperature of 212° by means of a lamp, or any other source of heat. Let the steam be conducted by a pipe C to a vessel A, which contains a quantity of water at the temperature of 32°. The steam issuing from the pipe is condensed by the cold water, and mixing with it gradually raises its temperature until it attains the temperature of 212°, after which the steam ceases to be condensed, and escapes in bubbles at the surface, as common air would if driven into the water from the pipe.

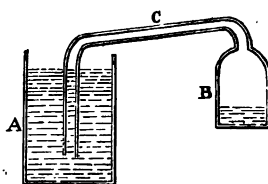


Fig. 268.

If the quantity of water in A be weighed before and after this process, its weight will be found to be increased in the ratio of 11 to 13. Thus 11 lbs. of water at 32°, mixed with 2 lbs. of water in the form of steam at 212°, have produced 13 lbs. of water at 212°, so that the 2 lbs. of water which were introduced in the form of steam at 212° have been changed from the vaporous to the liquid state, retaining, however, their temperature of 212°, and have given to 11 lbs. of water which were previously in A at 32° as much heat as has been sufficient to raise that quantity to 212°.

It follows, therefore, that any given weight of water in the form of steam at 212° contains as much heat latent in it as is sufficient to raise 5½ times its own weight of water from 32° to 212°, that is, through 180° of the thermometric scale.

If it be assumed that to raise a pound of water through 180° requires 180 times as much heat as to raise it one degree, it will follow that the quantity of latent heat contained in a pound of water in the form of steam at 212° is $5\frac{1}{2} \times 180 = 990$ times as much as would raise a pound of water through one degree.

This fact is usually expressed by stating that steam at 212° contains 990° of latent heat.

The same important fact can also be made manifest in the following manner. Let a lamp, or any source of heat which acts in a regular and uniform manner, be applied to a vessel containing any given quantity of water which is at 32° when the process commences, and let the time be observed which the lamp takes to raise the water to 212°. Let the lamp continue to act in the same uniform manner until all the water has been converted into steam, and it will be found that the time necessary for such complete evaporation will be exactly 5½ times that which was necessary to raise the water from the freezing to the boiling point. In a word, it will require 5½ times as long an interval to convert any given quantity of water into steam as it will take to raise the same quantity of water, by the same source of heat, from the freezing to the boiling point; and consequently it follows that 5½ times as much heat is absorbed in the evaporation of water as is necessary to raise it without evaporation through 180° of temperature.

519. Different experimental inquirers have estimated the heat rendered latent by water in the process of evaporation at 212° as follows: —

Watt	950°	Desprez	955°·8
Southern	945	Regnault	967·5
Lavoisier	1000	Fabre and Silbermann	964·8
Rumford	1004·8		

In round numbers it may therefore be stated that as much heat

is absorbed in converting a given quantity of water at 212° into steam as would be sufficient to raise the same quantity of water to the temperature of 1200° when not vaporised.

520. It was observed at an early epoch in the progress of discovery, that the heat absorbed in vaporisation was less as the temperature of the vaporising liquid was higher. Thus a given weight of water vaporised at 212° absorbs less heat than would the same quantity vaporised at 180°. It was generally assumed that the increase of latent heat, for lower as compared with higher temperatures, was equal to the difference of the sensible heats, and consequently that the latent heat added to the sensible heat, for the same liquid, must always produce the same sum. Thus, if water at 212° absorb in vaporisation 950° of heat, water at 262° would only absorb 900°, and water at 162° would absorb 1000°.

The simplicity of this result rendered it attractive; and, as the general result of experiments appeared to be in accordance with it, it was generally adopted. M. Regnault has, however, lately submitted the question, not only of the latent heat of steam, but also its pressure, temperature, and density, to a rigorous experimental investigation, and has obtained results entitled to more confidence, and which show that the sum of the latent and sensible heats is not rigorously constant.

521. The pressures and densities obtained by M. Regnault are in accordance with those given in (492.). The latent heats are given in the following table, where I have given their sums, and shown, what does not seem to have been hitherto noticed, that they increase by a constant difference:—

Temp.	Latent Heat.	Sum of Latent Heat and Sensible Heat.	Temp.	Latent Heat.	Sum of Latent Heat and Sensible Heat.
32°	1092·6	1124·6	248	939·6	1187·6
50	1080·0	1130·0	266	927·0	1193·0
68	1067·4	1135·4	284	914·4	1198·4
86	1054·8	1140·8	302	901·8	1203·8
104	1042·2	1146·2	320	889·2	1209·2
122	1029·6	1151·6	338	874·8	1212·8
140	1017·0	1157·0	356	862·2	1218·2
158	1004·4	1162·4	374	849·6	1223·6
176	991·8	1167·8	392	835·2	1227·2
194	979·2	1173·2	410	822·6	1232·6
212	966·6	1178·6	428	808·2	1236·2
230	952·2	1182·2	446	795·6	1241·6

It appears, therefore, that the sum of the latent and sensible heats is not constant, but increases by a constant difference,—a difference however which, compared with the sum itself, is very small, and for limited ranges of the thermometric scale, when extreme accuracy is not required, may be disregarded.

522. **The latent heat of the vapours of other liquids have been ascertained by MM. Fabre and Silbermann, and are given, as well as the specific heats, in the following table: —**

Names of Substances.	Temperature.	Specific Heat.	Latent Heat.	Names of Substances.	Temperature.	Specific Heat.	Latent Heat.
Water - - -	212°	1	964·8	Acid, formic - -	212°	0·65	304·2
Carburetted hydrogen	392	0·49	108	„ acetic - -	248	0·51	183·6
Ditto	482	0·50	108	„ butyric - -	327·2	0·41	207
Pyroligneous acid -	151·7	0·67	475·2	„ Valerianic -	347	0·48	187·2
Alcohol, absolute -	172·4	0·64	374·4	Ether, acetic - -	165·2	0·48	190·8
„ Valerianic -	172·4	0·59	217·8	Butyrate of Metylène	199·4	0·49	156·6
„ ethalic -	172·4	0·51	104·4	Essence of turpentine	312·8	0·47	124·2
Ether, sulphuric -	100·4	0·50	163·8	Térébène - -	312·8	0·52	120·6
„ Valerianic -	236·3	0·52	124·2	Oil of lemons - -	329	0·50	126

523. **Condensation of vapour.**—Since by continually imparting heat to any body in the liquid state, it at length passes into the form of vapour, analogy suggests that by continually withdrawing heat from a body in the vaporous state, it must necessarily return to the liquid state; and this is accordingly generally true. The vapour, being exposed to cold, is deprived of a part of that heat which is necessary to sustain it in the aeriform state, and a part of it is accordingly restored to the liquid form; and this continues until, by the continual abstraction of heat, the whole of the vapour becomes liquid: and as a liquid in passing to the vaporous form undergoes an immense expansion or increase of bulk, so a vapour in returning to the liquid form undergoes a corresponding and equal diminution of bulk. A cubic inch of water, transformed into steam at 212°, enlarges in magnitude to nearly 1700 cubic inches. The same steam being reconverted into water, by abstracting from it the heat communicated in its vaporisation, will be restored to its former bulk, and will form one cubic inch of water at 212°. Vapours arising from other liquids will undergo a like change, differing only in the degree of diminution of volume which they suffer respectively. The diminished space into which vapour is contracted when it passes into the liquid form, has caused this process to be called *condensation.*

524. The absorption of heat in the process by which liquids are converted into vapour will explain why a vessel containing a liquid that is constantly exposed to the action of fire can never receive such a degree of heat as would destroy it. A tin kettle containing water may be exposed to the action of the most fierce furnace, and remain uninjured; but if it be exposed, without containing water, to the most moderate fire, it will soon be destroyed. The heat which the fire imparts to the kettle containing water is immediately absorbed by the steam into which the water is converted. So long as water is contained in the vessel, this absorption of heat will continue; but if any part of the vessel not containing water

be exposed to the fire, the metal will be fused, and the vessel destroyed.

525. **Distillation.**—This process depends upon the successive evaporation and condensation of liquids, and is used for the purpose of separating liquids from impurities which they may hold in solution.

The process by which water is first converted into vapour and then restored to the state of water is called distillation, from a Latin word DISTILLATIO, which signifies "falling in drops." The conversion of the vapour into liquid in the condenser usually proceeds so slowly that the liquid falls from the spout of the condenser, not in a continuous stream, but in a succession of drops.

In the industrial arts, and in chemical laboratories, where water absolutely pure is needed in considerable quantities, its distillation is conducted in an apparatus which is represented in *fig.* 269.

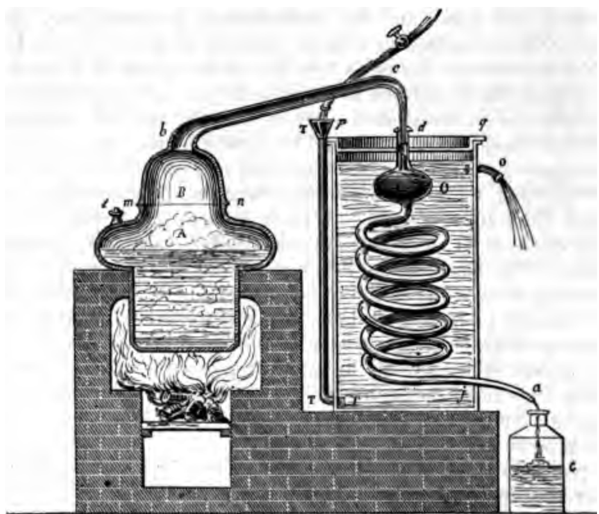


Fig. 269.

This distilling apparatus, or alembic, consists of a copper boiler, A, fixed in a brick furnace, having a dome-formed cover, B, adapted to it, from which a bent tube, *b c d*, proceeds, and is connected with a spiral tube called a *worm*. This worm is enclosed in a large cylindrical cistern, *p q j r*, constructed in metal, and which is kept constantly filled with cold water. The lowest part of the worm

passes out of this cistern near its bottom, and terminates at *a*, over the mouth of a jar, *c*, intended to receive the distilled water. An opening, *t*, having a steam-tight stopper, is provided in the boiler, through which the water to be distilled is introduced into it.

The vapour issuing from the boiler through the tube, *b c d*, passes into the worm, being first received by the vessel, o, where the condensation begins.

Passing next through the coils of the worm, it is exposed to the contact of its cold surface, and is entirely condensed and reduced to the liquid state before it arrives at the lower extremity, *a*, from which it trickles in drops into the jar, *c*.

The heat disengaged from the vapour in the process of condensation being constantly imparted to the water in the cistern *p q j r*, that water would be gradually warmed, and if it were not discharged and replaced by cold water, it would no longer keep the worm cold enough to condense the vapour. A supply of cold water is therefore introduced through a pipe, T T, while the heated water flows away through the pipe of discharge, *o*.

Heated water, being lighter bulk for bulk than cold water, will float upon the latter without mixing with it, unless the liquid be agitated. The cold water, therefore, being introduced at the lowest part, T, of the cistern, will form the inferior strata, while the heated water will collect at the superior strata, and, being pressed upwards by the cold water, will flow out at *o*. The supply pipe, *p*, which feeds the pipe T T, and the discharge pipe, *o*, may be, and generally are, so regulated that the water discharged from *o* is very little below the temperature of the vapour coming from the boiler, while the water of the lowest strata is as cold as the external atmosphere. The vapour, therefore, which enters at *d*, is at first only partially condensed, the condensation being rapidly increased as, winding through the worm, it passes in contact with a surface colder and colder until, at length arriving at the lowest coil, it is wholly condensed.

The heated water which flows from the discharge pipe, *o*, may be used to feed the boiler, B; and being already at a high temperature, an economy of fuel is thus effected.

When extreme purity is required in the distilled water, it is evaporated at a temperature lower than 212°, because at that temperature a certain small portion of the foreign matters which it holds in solution sometimes go over in the vaporous state through the worm, and are ultimately deposited in the jar, *c*. The lower the temperature at which the water in the boiler is evaporated, the less of this impurity will pass through the worm.

By these expedients, with proper precautions, water absolutely pure, and entirely free from all foreign matter, may be obtained.

526. **Apparatus to distil volatile liquids.** — In physical researches it is frequently necessary to distil very volatile liquids, the vapour of which would be wasted or lost if it were not condensed. In such cases apparatus for distillation such as those represented in *figs*. 270. and 271., are generally used in the laboratory of M. Regnault. In *fig*. 270. the globular glass flask A, placed upon a charcoal furnace, contains the liquid to be distilled; it is connected by a bent tube *a b c* with a condensing

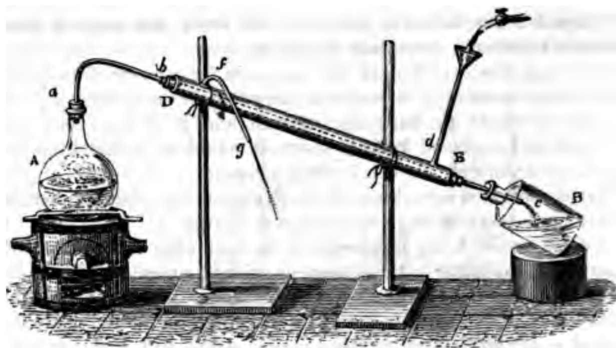


Fig. 270.

vessel B. This tube, *a b c*, is surrounded by a larger tube, D E, which is made water-tight at the ends; this tube, which is usually

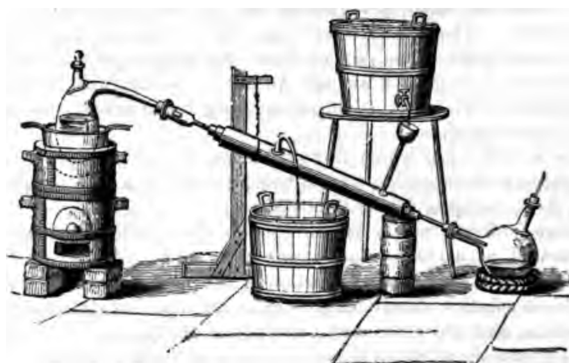


Fig. 271.

made of tin, is kept filled with cold water by a lateral tube *d*, and the water is discharged from it by another lateral tube *f g*. The

vapour, in passing through the tube *a b c*, is condensed by the cold to which it is exposed between D and E.

In *fig.* 271. another variety of the same apparatus is shown, which is used when the vessels in which the liquids are distilled are liable to be broken by the unequal action of the heat when in immediate contact with the charcoal. In the apparatus shown in *fig.* 271., the flask A is replaced by a tubulated retort, which is immersed in a sand bath heated by the charcoal. Another tubulated retort replaces the vessel B.

When the quantity of liquid to be distilled is not considerable, a more simple apparatus, such as that represented in *fig.* 272., may

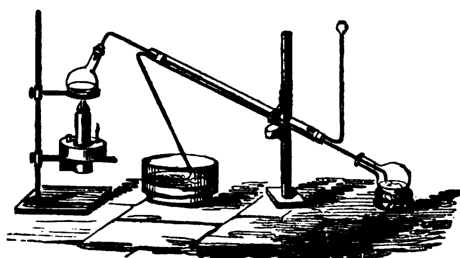


Fig. 272.

be used, where an Argand lamp replaces the charcoal furnace, the other parts of the apparatus being easily intelligible after what has been explained.

527. **Crystallisation produced by distillation.**—The process of distillation supplies an easy and convenient means of obtaining bodies in a crystallised state. It is found that, when solid bodies are dissolved in water, there is a certain limit to the quantity which can be held in solution, and that, if a greater quantity be thrown into the water, it will sink to the bottom without being dissolved. This is a fact which any one can ascertain by dissolving common salt in water. When so much of the solid is supplied as the water is capable of dissolving, the solution is said to be *saturated*, and the particular proportion of the quantity dissolved to the entire quantity of water is called the point of saturation.

Now it is found that, in general, the point of saturation varies with the temperature of the water; the higher that temperature is, the higher will the point of saturation be, or, what is the same, the greater will be the quantity of the solid which a given quantity of water can hold in solution. If, therefore, water at the boiling point be saturated, it must deposit, according as it cools, a certain quantity of the substance it holds in solution; and it is

found, in general, that the substance thus deposited will be in a state of crystallisation. But crystallisation may also be produced by evaporation, independently of any change of temperature. Thus, for example, if water at the boiling point be saturated with salt, the quantity of water being diminished by that which escapes in the form of steam, the remainder being incapable of holding the same quantity of salt in solution, a part of the salt will be deposited in the solid form, and the part thus deposited will increase as the water is evaporated.

This effect produces very injurious consequences in the boilers of steam vessels; which, being supplied with sea water, holding salts of different sorts in solution, the continued evaporation at length raises the water in the boiler to the point of saturation, after which salt will be deposited, which, accumulating in the boiler, will intercept more or less of the heat, and thus produce waste of fuel and other injurious consequences.

528. In physical researches it is often required to obtain in a separate state the substances which water holds in solution. For this purpose the solution is poured into a porcelain cup, which is placed over a spirit lamp, as shown in *fig.* 273.; and the water



Fig. 273.

being thus evaporated, the substance held in solution remains in the cup. In chemical analyses, however, where it is necessary to obtain a rigorous estimate of the quantity held in solution, this process requires to be conducted with many precautions. Thus, the liquid must not be raised to the boiling point, because in that case the steam bubbles produced at the bottom of the cup would rise with such force as to scatter, in the form of spray, more or less of the substance which it is necessary to preserve. Sometimes the cup containing the solution to be evaporated is placed in another containing water, by which means the heat imparted to the former is moderated and regulated. In other cases the water

is omitted, and the cup containing the solution is suspended in a cup of copper, which is empty, or which, more properly speaking, is filled with air. In other cases, again, the cup containing the solution to be evaporated is placed in a sand bath raised to a moderate temperature by a wood fire.

529. **Freezing by evaporation.**—The evaporation of liquids is retarded by the pressure of the air surrounding them, and is consequently promoted when that pressure is diminished or removed. A method of producing artificial ice is founded upon this principle.

A cup of unglazed porcelain, containing water, is placed upon a large glass dish containing sulphuric acid. The dish and cup are then placed upon the plate of an air pump (*fig.* 274.), and being covered by a receiver, the air is exhausted. The water, being relieved from the atmospheric pressure, freely evaporates, and the receiver would soon be filled with an atmosphere of its vapour, the pressure of which would arrest the evaporation; but the sulphuric acid, having an attraction for water, absorbs the vapour as fast as it is produced, and the water being thus free from pressure, the evaporation continues.

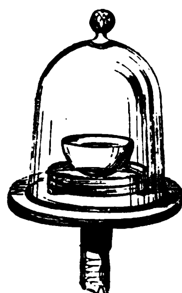


Fig. 274.

But in the change from the liquid to the vaporous state a large quantity of heat is absorbed and rendered latent, as already explained, and all this heat must be taken from the water which remains unevaporated. Thus, for every drop of water which is converted into vapour, the water which remains in the cup will be deprived of as much heat as would be sufficient to raise the temperature of a similar drop a thousand degrees higher if it were not evaporated. This great loss of heat causes the water which remains unevaporated in the cup to fall in temperature and soon to congeal.

530. **Uses of latent heat of steam.** — The latent heat of steam may be used with convenience for many domestic purposes. In cookery, if the steam raised from boiling water be allowed to pass through meat or vegetables, it will be condensed upon their surface, imparting to them the latent heat which it contained before its condensation, and thus they will be as effectually boiled as if they were immersed in boiling water.

531. In dwelling-houses, where pipes convey cold water to different parts of the building, steam pipes carried through the building will enable hot water to be procured in every part of it with speed and facility. The cock of the steam pipe being immersed in a vessel containing cold water, the steam which escapes from it will be condensed by the water, which, receiving the latent

heat, will soon be raised to any required temperature below the boiling point. Warm baths may thus be prepared in a few minutes, the water of which would require a long period to boil.

532. The variations of temperature incident to any part of the globe are included within narrow limits, and these limits determine the bodies which are found to exist there most commonly in the solid, liquid, or gaseous state.

A body whose boiling point is below the lowest temperature of the climate must always exist in the state of vapour or gas; and one whose point of fusion is above the highest temperature must always be solid. Bodies whose point of fusion is below the lowest temperature, while their boiling point is above the highest temperature, will be permanent liquids. A body whose point of fusion is a little above the lowest limit of the temperature, will exist generally as a liquid, but occasionally as a solid. Water in these climates is an example of this. A liquid, on the other hand, whose boiling point is a little below the highest limit of temperature, will generally exist in the liquid, but occasionally in the gaseous form. Ether in hot climates is an example of this, its boiling point being 98°.

Some bodies are only permanently retained in the liquid state by the atmospheric pressure. Ether and alcohol are examples of these. If these liquids be placed under the receiver of an air pump, and the pressure of the air be partially removed, they will boil at the common temperature of the air.

CHAP. VII.

CONDUCTION.

533. **Conductors.** — When heat is imparted to one part of any mass of matter, the temperature of that part is raised above that of the other parts. This inequality, however, is only temporary. The heat gradually diffuses itself from particle to particle throughout the volume of the body, until a perfect equilibrium of temperature has been established. Different bodies exhibit a different facility in this gradual transmission of heat. In some it passes more rapidly from the hotter to the colder parts than in others. Those bodies in which it passes easily and rapidly are *good conductors*. Those in which the temperature is equalised slowly are *bad conductors*.

534. Let A B (*fig.* 275.) be a bar of metal having a large cavity formed at its extremity A, and having a series of small

cavities formed at equal distances throughout its length at T_1, T_2, T_3, &c. Let the bulbs of a series of thermometers be immersed in mercury in these cavities severally. These thermometers will all indicate the same temperature, being that of the bar A B.

Let the large cavity A, at the end of the bar, be filled with mercury at a high temperature, 400°, for example.

After the lapse of some minutes the thermometer T will begin

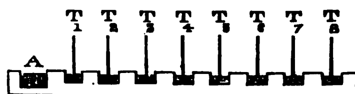


Fig. 275.

to rise; after another interval the thermometer T_2 will begin to be affected; and the others, T_3, T_4, &c., will be successively affected in the same way; but the thermometer T_1, by continuing to rise, will indicate a higher temperature than T_2, and T_2 a higher temperature than T_3, and so on. After the lapse of a considerable time, however, the thermometer T_1 will become stationary. Soon afterwards T_2, having risen to the same point, will also become stationary; and in the same manner all the others, having successively risen to the same point, will become stationary.

If several bars of different substances of equal dimensions be submitted to the same process, the thermometers will be more or less rapidly affected, according as they are good or bad conductors.

Another form of apparatus for a like purpose is shown in *fig.* 276. A series of thermometers, as before, are inserted in cavities

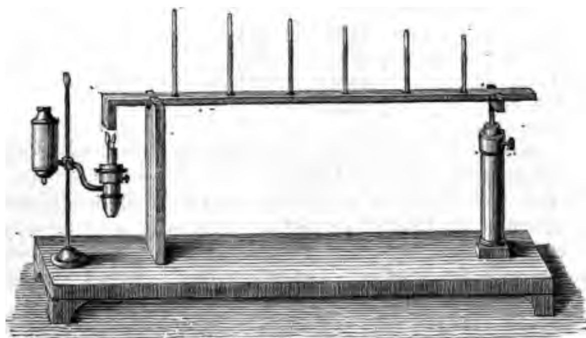


Fig. 276.

filled with mercury in a bar supported horizontally, one end of which is heated by a lamp. The progressive propagation of the heat is indicated as before.

An apparatus by which this is exhibited in a striking manner is represented in *fig.* 277. A series of rods of equal length and thickness are inserted at the same depth in the side of a rectangular vessel, passing across the interior of the vessel to the opposite side. The rods, which are silver, copper, iron, glass, porcelain, wood, &c., are previously covered with a thin coating of wax, or any other substance which will melt at a low temperature. Boiling water or heated mercury is poured into the vessel, and imparts heat to those parts of the rods which extend across it. It is found that the heat, as it passes by conduction along the rods, melts the wax from their surface. Those which are composed of the best conductors — silver, for example — will melt off the wax most rapidly; the less perfect conductors less rapidly; and on the rods composed of the most imperfectly conducting materials, such as glass or porcelain, the wax will not be melted beyond a very small distance from the point where the rod enters the vessel.

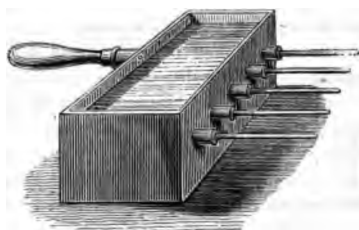


Fig. 277.

535. **Table of conducting powers.** — By experiments conducted on this principle, it has been found that the conducting powers of the subjoined substances are in the ratio here expressed, that of gold being 100: —

Gold	100·00	Tin	30·38
Platinum	98·10	Lead	17·96
Silver	97·30	Marble	2·34
Copper	89·82	Porcelain	1·22
Iron	37·41	Brick earth	1·13
Zinc	36·37		

It is evident, therefore, that metals are the best conductors of heat, and in general the conducting power increases with the specific gravity, as will appear by comparing the preceding numbers with those given in the table of specific gravity (91.). It is also found that among woods, with some exceptions, the conducting power increases with the density. The conducting power of nut wood, however, is greater than that of oak.

Bodies of a porous, soft, or spongy texture, and more especially those of a fibrous nature, such as wool, feathers, fur, hair, &c., are the worst conductors of heat.

536. Liquids are almost absolute nonconductors. Let a tall narrow glass vessel, having a cake of ice at the bottom, be filled

with strong alcohol at 32°. Let two thermometers be immersed in it, one near the surface, and the other at half the depth. If the alcohol be inflamed at the surface, the thermometer near the surface will rise, but that which is at the middle of the depth will be scarcely affected, and the ice at the bottom will not be dissolved.

Bodies in the gaseous state are probably still more imperfect conductors than liquids.

The equilibrium of temperature is, however, maintained in liquid and gaseous bodies by other principles, which are more prompt in their action than the conductibility even of the solids which possess that quality in the highest degree. When the strata of fluids, whether liquid or gaseous, are heated, they become by expansion relatively lighter than those around them. If they have any strata above them, which generally happens, they rise by their buoyancy, and the superior strata descend. There are thus two systems of currents established, one ascending and the other descending, by which the heat imparted to the fluid is transfused through the mass, and the temperature is equalised.

537. The conducting power of all bodies is diminished by pulverising them, or dividing them into fine filaments. Thus sawdust, when not too much compressed, is one of the most perfect nonconductors of heat. A casing of sawdust is found to be the most effectual method of preventing the escape of heat from the surface of steam boilers and steam pipes.

If, however, the sawdust be either much compressed on the one hand, or too loosely applied on the other, it is not so perfect a nonconductor. In the one case, the particles, being brought into closer contact, transmit heat from one to another; and in the other case, the air circulating too freely among them, the currents are established by which the heat is transfused through the mass.

To produce, therefore, the most perfect nonconductor, the particles of the body must have naturally little conductibility, and they must be sufficiently compressed to prevent the circulation of currents of air among them, and not sufficiently compressed to give them a facility of transmitting heat from particle to particle by contact.

538. **Examples.** — The animal economy presents numerous and beautiful examples of the fulfilment of these conditions. It is generally necessary to the well-being of the animal to have a temperature higher than that of the medium which it inhabits. In the animal organisation, there is a principle by which heat is generated. This heat has a tendency to escape, and to be dissipated at the surface of the body, and the rate at which it is dissipated depends on the difference between the temperature of the surface of the body and the temperature of the surrounding medium.

If this difference were too great, the heat would be dissipated faster than it is generated, and a loss of heat would take place, which being continued to a certain extreme, would destroy the animal.

Nature has provided an expedient to prevent this, which varies in its efficiency according to the circumstances of the climate and the habits of the animal.

539. The plumage of birds is composed of materials which are bad conductors of heat, and are so disposed as to contain in their interstices a great quantity of air without leaving it space to circulate. For those species which inhabit the colder climates a still more effectual provision is made, for, under the ordinary plumage, which is adapted to resist the wind and rain, a still more fine and delicate down is found, which intercepts the heat which would otherwise escape through the coarser plumage. Perhaps the most perfect insulator of heat is swansdown.

540. The wool and fur of animals are provisions obviously adapted to the same uses. They vary not only with the climate which the species inhabits, but in the same individual they change with the season. In warm climates the furs are in general coarse and sparse, while in cold countries they are fine, close, light, and of uniform texture, so as to be almost impermeable to heat.

541. The vegetable, not less than the animal kingdom, supplies striking illustrations of this principle. The bark, instead of being hard and compact, like the wood which it clothes, is porous, and in general formed of discontinuous laminæ and fibres, and, for the reasons already explained, is a bad conductor of heat, and thus prevents such a loss of heat from the surface of the wood under it as would be injurious to the tree.

A tree stripped of its bark perishes, as an animal would if stripped of its fleece, or a bird of its plumage.

542. Man is endowed with faculties which enable him to fabricate for himself covering similar to that which nature has provided for other animals; and where his social condition is not sufficiently advanced for the accomplishment of this, his object is attained by the conquest of inferior animals whose clothing he appropriates.

Clothes are generally composed of some light nonconducting substances which protect the body from the inclement heat or cold of the external air. In summer, clothing keeps the body cool; in winter, warm. Woollen substances are worse conductors of heat than cotton, cotton than silk, and silk than linen. A flannel shirt more effectually intercepts heat than a cotton, and a cotton than a linen one.

543. What the plumage does for the bird, wool for the animal, and clothing for the man, snow does in winter for the soil. The farmer and the gardener look with dismay at a hard and continued

frost which is not preceded by a fall of snow. The snow is nearly a nonconductor, and, when sufficiently deep, may be considered as absolutely so. The surface may therefore fall to a temperature greatly below 32°, but the bottom in contact with the vegetation of the soil does not share in this fall of temperature, remaining at 32°, a temperature at that season not incompatible with the vegetable organisation. Thus the roots and young shoots are protected from a destructive cold.

544. The gardener who rears exotic vegetables and fruit trees, protects them from the extreme cold of winter by coating them with straw, matting, moss, and other fibrous materials which are nonconductors.

545. If we would preserve ice from dissolving, the most effectual means would be to wrap it in blankets. Ice-houses may be advantageously surrounded with sawdust, which keep them cold by *excluding* the heat, by the same property in virtue of which it keeps steam boilers warm by *including* the heat.

Air being a bad conductor of heat, ice-houses are sometimes constructed with double walls, having a space between them. This expedient is still more effectual, if the space be filled with loose sawdust.

546. Glass and porcelain are slow conductors of heat, which explains the fact that vessels of this material are so often broken by suddenly pouring hot water into them. If it be poured into a glass tumbler, the bottom, with which the water first comes in contact, expands; but the heat not passing freely to the upper part, this expansion is limited to the bottom, which is thus forced from the upper part, and a crack is produced.

547. When wine-coolers have a double casing, the external space is filled with a nonconductor.

548. When a solid body, a globe for example, is heated at the surface, the heat passes gradually from the surface to the centre. The temperature of the superficial stratum is greater, and the temperature of the centre less than those of the intermediate parts, and the temperature of the successive strata are gradually less, proceeding from the surface to the centre.

But if the globe be previously heated, so as to have an uniform temperature from the centre to the surface, and be allowed to cool gradually, the superficial stratum will first fall some degrees below the stratum within it. This latter will fall below the next stratum proceeding inwards; and in the same way each successive stratum proceeding from the surface to the centre will attain a temperature a little lower than the stratum under it, the temperatures augmenting from the surface to the centre.

After an interval, of greater or less duration, according to the

magnitude of the globe, the conductibility and specific heat of the matter of which it is composed, the temperature to which it has been raised, and the temperature of the medium, it will be reduced to an uniform temperature, which will be that of the surrounding medium.

549. If a mass of fluid metal be cast in a spherical mould, the surface only will be solidified in the first instance. It will become a spherical shell, filled with liquid metal. As the cooling proceeds, the shell will thicken, and after an interval of time, the length of which will depend on the circumstances above mentioned, the ball will become solid to its very centre, the last portion solidified being that part of the metal which is at and immediately around the centre.

It is evident that the superficial stratum will first cease to be incandescent; and in the same way each successive stratum proceeding from the surface to the centre will cease to be incandescent before the stratum within it.

If in the process of cooling, and after the globe ceases to be red hot, it were cut through the centre, it would be found that the central parts would be still incandescent; and if its magnitude were sufficiently considerable, it would be found that even after the superficial stratum had been reduced to a moderate temperature, strata nearer the centre would be red hot, and the central part still fluid.

550. The interval which must elapse before the thermal equilibrium would be established might be hours, days, weeks, months, years, or even a long succession of ages, according to the magnitude and physical qualities of the material composing the globe.

551. The cylinder of the hydraulic press by which the tubes of the Britannia bridge were elevated was formed of a mass of fluid iron weighing 22 tons. This enormous casting, after being left in the mould for three days and nights, was still red hot at the surface. After standing to cool in the open air for ten days, it was still so hot that it could only be approached by men well inured to heat.

552. The torrents of liquid lava which flow from volcanos become solid on their external surface only to a certain thickness. The lava in the interior of this shell still continues fluid. The stream of lava thus forms a vast tube, within which that portion of the lava still liquid flows for a long period of time. Months and even years sometimes elapse before the thermal equilibrium of these volcanic masses is established.

553. The globe of the earth itself presents a stupendous example of the play of these principles. The vicissitudes of temperature incidental to the surface extend to an inconsiderable depth. At the depth of a hundred feet, in our climates, they are completely

effaced. At this depth the thermometer no longer varies with the seasons. In the rigour of winter and the ardour of summer it stands at the same point. This stratum, which is called the first stratum of invariable temperature, is found to be at Paris at the depth of 86 feet. The thermometer in the vaults under the Observatory at that depth has continued without variation at $11^\circ\cdot82$ cent. $= 53^\circ\cdot276$ Fahr. for more than fifty years.

554. At greater depths the temperature increases, but is always invariable for the same depth. An increase of temperature takes place in descending, at the rate of one degree for every $54\frac{1}{2}$ feet of depth. Thus, the water which issues from the Artesian wells at Grenelle near Paris, and which rises from a depth of 1800 feet, has a constant temperature of $27^\circ\cdot7$ cent. $= 82^\circ$ Fahr.

It is apparent that the earth is a globe undergoing the gradual process of cooling, and that each stratum proceeding inwards towards the centre augments in temperature. It follows, therefore, that a part at least of the superficial heat of the earth proceeds from within. It is certain, nevertheless, by taking into account all the conditions of the question, that the cooling goes on so slowly as to have no sensible influence on the temperature at the surface, which is therefore governed by the solar heat, and the heat of the medium or space in which our globe, in common with the other planets, moves. It has been computed that the quantity of central heat which reaches the surface in a year would not suffice to dissolve a cake of ice a quarter of an inch thick.

555. The globe of the earth, therefore, manifesting the effects of a mass which, having been at some antecedent period at an elevated temperature, is undergoing the process of gradually cooling from the surface inwards, it is nearly certain that its central parts may be still in a state of incandescence or fusion.

CHAP. VIII.

RADIATION.

556. Heat, like light, is propagated through space by radiation in straight lines, and its rays, like those of light, are subject to transmission, reflection, and absorption by such bodies as they encounter in various degrees.

All that is established in optics respecting the reflection of light from unpolished, perfectly and imperfectly polished surfaces, its refraction by transparent media, its interference, inflexion, and

polarisation, may, with little modification, be applied to the rays of heat submitted to like conditions.

557. **Thermal analysis of solar light.** — It is demonstrated in our treatise on "Optics" that solar light is a compound principle, consisting of rays differing one from another, not only in their luminous qualities of colour and brightness, but also in their thermal and chemical properties.

Let S S, *fig.* 278., represent a pencil of solar light transmitted through a prism A B C, so as to be resolved into a divergent fan of rays, and to form a spectrum, as described in "Optics." Let

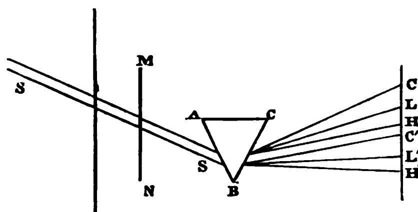


Fig. 278.

L and L′ be the limits of the luminous spectrum. If the bulb of a thermometer be placed at L, it will not indicate any elevation of temperature; and if it be gradually moved downwards along the spectrum, it will not begin to be sensibly affected until it arrives at the boundary of the violet and blue spaces, where it will show an increased temperature. As it is moved downwards from this point, the temperature will continue to increase until it is brought to the lower extremity L′ of the luminous spectrum. If it be then removed below this point, instead of falling to the temperature of the medium around the spectrum, as might be expected, and as would in fact happen if no rays of heat transmitted through the prism passed below L′, it will descend slowly and gradually, and will in some cases even show an increased temperature to a certain small distance below L′. In fine, it will be found that the thermometer will not fall to the temperature of the surrounding medium until it arrives at a certain distance H′ below L′, the extremity of the luminous spectrum.

558. From this and other similar experiments, it is inferred that thermal rays which are not luminous, or at least not sensibly so, enter into the composition of solar light, and that these rays are differently refrangible, their mean refrangibility being less than the mean refrangibility of the luminous rays.

It is also demonstrated in "Optics" that the chemical rays which enter into the composition of solar light are also differently refran-

gible, and have a mean refrangibility greater than that of the luminous rays.

559. According to this view of the constitution of solar light, the prism A B C must be regarded as producing three spectra, a chemical spectrum C C′, a luminous spectrum L L′, and a thermal spectrum H H′. The luminous or chromatic spectrum, the only one visible, lies between, and is partly overlaid by, the other two, the chemical spectrum extending a little above, and the thermal a little below it. If we imagine a screen M N placed before the prism, composed of a material pervious to the luminous, but impervious to the chemical and thermal rays, then the luminous spectrum L L′ alone will remain, and neither a thermometer nor the chloride of silver, nor any other chemical substance, will be affected when exposed in it. If the screen M N be pervious only to the thermal rays, then the luminous and chemical rays will be intercepted, and the thermal spectrum H H′ alone will be manifested. The thermometer exposed in it will indicate the variations of calorific influence already explained, showing the greatest thermal intensity at or near that point at which the red extremity of the luminous spectrum would have been found, had the luminous rays not been intercepted.

560. If prisms composed of different materials be used, it will be found that the mean refrangibility of the thermal rays will vary according to the material of the prism and heat; consequently, the position of the point of greatest thermal intensity will be subject to a like variation.

If a hollow prism be filled with water or alcohol, the point of greatest thermal intensity will be about the middle of the yellow space of the luminous spectrum. If a prism of sulphuric acid, or a solution of corrosive sublimate, be used, it will be in the orange space. With a crown glass prism it will be in the red space; and with one of flint glass, a little below that space.

561. In the preceding explanation, the solar light is regarded as consisting of three distinct species of rays, the chemical, the luminous, and the thermal. It is not necessary, however, for the explanation of these phenomena, to adopt this hypothesis. The light may be considered as consisting of rays which, differing in refrangibility, possess the other physical qualities also in different degrees. So far as the sensibility of thermometers enables us to detect the thermal property, it ceases to exist at a certain point, near the boundary of the blue and violet spaces; but the diminution of thermal intensity, in approaching this point, as indicated by the thermometer, is very gradual; and it cannot be denied, that a thermal influence may exist above that point, which is, nevertheless, too feeble to affect the thermoscopic tests which are

used. In the same manner it may be maintained that a chemical influence may exist below the point C′, but too feeble to affect any of the tests which have been applied to it.

But it may be asked, if all the component rays possess all the properties in different degrees, how happens it that the chemical rays above L, and the thermal rays below L′, are not visible? To this it may be answered that the presence of the luminous quality is determined by its effect on the eye; and the discovery of its presence must therefore depend on the sensibility of that organ. To pronounce that there are no luminous rays beyond the limits of the chromatic spectrum, would be equivalent to declaring the sensibility of the eye to be unlimited. Now, it is notorious that the sensibility of sight, in different persons, is different; and, even in the same individual, varies at different times. Circumstances render it highly probable that many inferior animals have a sensation of light, and a perception of visible objects, where the human eye has none; and it is therefore consistent with analogy to admit the possibility, if not the probability, that the invisible thermal rays below L′, and the invisible chemical rays above L, may be of the same nature as the other rays of the spectrum, all enjoying the luminous, thermal, and chemical properties in common; the apparent absence of these properties in the extreme rays being ascribable solely to the want of sufficient sensibility in the only tests of their presence which we possess.

Fortunately, however, the deductions of physical science, though they may be facilitated by these and other hypotheses, are not dependent on them, but on observed facts and phenomena, and cannot, consequently, be shaken by the failure of such theories.

562. If a hole be made in the screen upon which the prismatic spectrum is thrown, in the space L′ H′ below the red extremity of the spectrum upon which the invisible thermal rays fall, these rays will pass through it, and may be submitted to all the experiments on reflection, refraction, inflexion, interference, and polarisation. This has been done, and they have been found to manifest effects similar to those exhibited by luminous rays.

563. It is shown in optics that when a body is either luminous, like the sun, or illuminated, like the moon, each point upon its surface is an independent centre of radiation or *focus* from which rays of light diverge or radiate in all directions. It is the same with regard to heat. All bodies, whatever be their state or condition, contain more or less of this physical principle; and rays of heat accordingly issue from every point upon their surface, as from a focus, and diverge or radiate in all directions through the surrounding space.

564. This being the case, it would follow that by such continual

and unlimited radiation, bodies would gradually lose their heat, and indefinitely fall in temperature. It must be considered, however, that such radiation, being universal, each body, while it thus radiates heat, receives upon its surface the rays of heat which proceed from other bodies around it. So many of these rays as it absorbs tend to increase its temperature, and to replace the heat dispersed by its own radiation. There is thus between body and body a continual interchange of heat by radiation; and according as this interchange is equal or unequal, the temperature of the radiating body will rise or fall. If it radiate more than it absorbs, it will fall; if less, it will rise. If it absorb as much exactly as it radiates, its temperature will be maintained stationary.

565. Radiation takes place altogether from points either on the surface or at a very small depth below it. The circumstances which affect it have been made manifest by a beautiful series of experiments made by the late Sir John Leslie. The principles on which his mode of experimenting was founded are easily explained.

566. **Reflection of heat.**— Let a cubical canister of tin (*fig.* 279.) be placed on the axis of a parabolic metallic reflector M, in the focus *f* of which is placed the bulb of a sensitive differential thermometer. If the canister be placed with one of its sides at right angles to the axis of the reflector, and be filled with boiling water, the thermometer will instantly show an increase of temperature caused by the heat radiated from the surface of the canister, and collected into a focus upon the ball by the reflector. A perspective view of the apparatus is given in *fig.* 280.

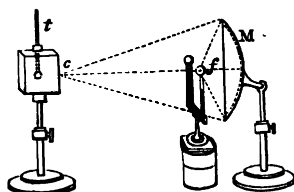


Fig. 279.

The experiment may be varied by filling the canister with liquids at all temperatures, with snow, and with freezing mixtures having various degrees of artificial cold. The surface of the canister may be varied in material by attaching to it different substances, such as paper, metallic foil, glass, porcelain, &c. It may be varied in texture by rendering it rough or smooth, and in colour by any colouring matter. In this way the influence of all these physical conditions upon the radiation from the surface may be, and has been, ascertained.

The results of such experimental researches have been briefly as follows: —

567. I. The rate at which the radiating body loses or gains temperature, other things being the same, is proportional to the

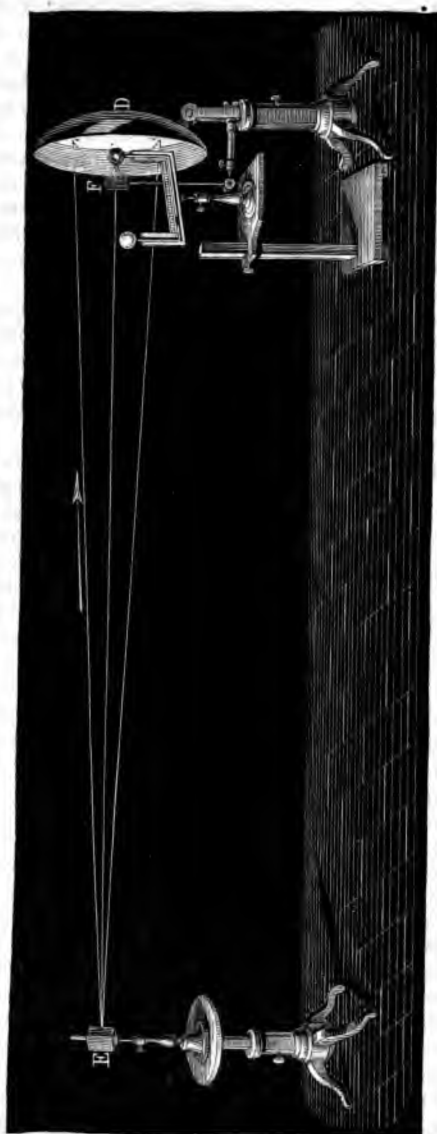


Fig. 280.

difference between its own temperature and that of the surrounding medium, where this difference is not of very extreme amount.

568. II. The intensity of the heat radiated is, like that of light, other things being the same, inversely as the square of the distance from the centre of radiation.

569. III. The radiating power varies with the nature of the surface, and its degree of polish or roughness. In general, the more polished a surface is, the less will be its radiation. Whatever tarnishes or roughens the surface of metal, increases its radiation. Metallic are in general less powerful radiators than non-metallic surfaces.

570. When the rays of heat encounter any surface, they are more or less reflected from it. Surfaces, therefore, in relation to heat, are perfect or imperfect, good or bad reflectors.

In the experiments above described, the reflecting powers of different surfaces were ascertained by constructing the concave reflector M of different materials, or by coating its surface variously, or, in fine, by submitting its surface to any desired physical conditions. Thus, when a reflector of glass is substituted for one of metal, the radiating surface of the canister remaining the same, it is found that the effect on the thermometer is diminished. Glass is, therefore, a less perfect reflector than metal. If the surface of the reflector be coated with lampblack, no effect whatever is produced on the thermometer. Such a surface does not, therefore, reflect the thermal rays.

571. To determine the physical conditions which affect the absorbing power of a surface, it is only necessary, in the experiment above described, to vary the surface of the ball *f* of the thermometer, which is placed in the focus of the reflector, for, as the heat is radiated by *c* and reflected by M, it is absorbed by *t*. By coating the ball of the thermometer, therefore, with metallic foil, paper, lampblack, and other substances, and by rendering it in various degrees rough and smooth, the effects of these modifications on the thermometer are rendered manifest, and the comparative absorbing powers are ascertained.

In this way it has been ascertained that the same physical conditions which increase the radiation and diminish the reflection, increase the absorption. The best radiators are the most powerful absorbers and the most imperfect reflectors.

572. In the following table, the numbers in the first column express the radiating and absorbing powers of various substances, that of a surface covered with the smoke of a lamp being expressed by 100. The absorbing power of this surface is complete. The

reflecting power is, as will be observed, the complement of the absorbing power.

Names.	Radiating and absorbing Powers.	Reflecting Power.	Names.	Radiating and absorbing Powers.	Reflecting Power.
Smoke-blackened surface	100	0	Metallic mirrors a little tarnished	17	83
Carbonate of lead	100	0	" nearly polished	14	86
Writing paper	98	2	Brass cast, imperfectly polished	11	89
Glass	90	10	" hammered, "	9	91
China ink	85	15	" " highly polished	7	93
Gumlac	72	28	" cast, "	7	93
Silver foil on glass	27	73	Copper coated on iron	7	93
Cast iron polished	25	75	" varnished	14	86
Mercury (nearly)	23	77	" hammered or cast	7	93
Wrought iron polished	23	77	Gold plating	5	95
Zinc, polished	19	81	Gold deposited on polished steel	3	97
Steel "	17	83	Silver, hammered and well polished	3	97
Platinum, thick coat, imperfectly polished	24	76	Silver, cast, and well polished	3	97
" plate on copper	17	83			
" leaves	17	83			
Tin	14	86			

573. The numbers given in this table, which will be observed to differ considerably from those determined by Leslie and others, have been obtained by the recent elaborate experimental researches of MM. De la Provostaye and Desains. In these experiments an anomalous circumstance was observed on varying the angle of incidence of the thermal rays. It was found that, in the case of glass, the proportion of rays reflected increased with the angle of incidence, as happens with luminous rays, but that with polished metallic surfaces, the same proportion was reflected at all incidences up to 70°, and beyond this limit the proportion reflected, instead of increasing, as would have been expected, was greatly diminished.

574. From all that has been here explained it will be apparent that the state of thermal equilibrium is maintained among any system of bodies by a continual interchange of heat by radiation and absorption. The heat which each body receives from others in its presence, it partly absorbs and partly reflects. Those rays which it absorbs tend to raise its temperature; and this temperature would soon rise above that which the thermal equilibrium requires, but that the body radiates heat from all points of its surface ; and the total quantity thus radiated is equal to the total quantity absorbed. If either of these quantities were permanently greater or less than the other, the temperature of the body would either indefinitely rise, or indefinitely fall, according as the heat absorbed or radiated might be in excess.

If a body, at any given temperature, be placed among other

bodies, it will immediately affect them *thermally*, just as a candle brought into a room illuminates all bodies in its presence, with this difference, however, that if the candle be extinguished, no more light is diffused by it; but no body can be *thermally extinguished*. All bodies, however low be their temperature, contain heat, and therefore radiate it.

575. **Erroneous hypothesis of radiation of cold.** — If a ball of ice be brought into the presence of a thermometer, the thermometer will fall; and hence it was erroneously inferred that the ice emitted *rays of cold*. The effect, however, is otherwise explained. The ice and the ball of the thermometer both radiate heat, and each absorbs more or less of what the other radiates towards it. But the ice, being at a lower temperature than the thermometer, radiates less than the thermometer, and therefore the thermometer absorbs less than the ice, and consequently falls.

If the thermometer placed in presence of the ice had been at a lower temperature than the ice, it would, for like reasons, have risen. *The ice in that case would have warmed the thermometer*.

576. **Transmission of heat.** — When rays of heat are incident on the surfaces of certain media, they penetrate them in greater or less quantity, according to the nature and properties of the medium, just as rays of light pass through bodies which are more or less transparent or diaphanous.

Media which are pervious to heat are said to be *diathermanous*, and those which are impervious are called *athermanous*.

Bodies are diathermanous in different degrees, or altogether athermanous, according to their various physical characters, their thickness, the state of their surface, the nature of the heat which is incident upon them, and other conditions.

577. **Melloni's thermoscopic apparatus.** — Nearly all the knowledge we possess in this branch of the physics of heat is the result of the recent researches of M. Melloni. The thermoscopic apparatus contrived and applied with singular felicity and success by him, consisted of a thermo-galvanic pile acting upon a highly sensitive galvanometer. It will be explained hereafter that if the thermal equilibrium be disturbed in certain metallic combinations, an electric current will be produced, the intensity of which will be proportional to the difference of temperature, and that the force of such a current can be measured by the deviation it produces in a magnetic needle, round which it is conducted spirally upon a coil of metallic wire coated with a nonconducting substance.

The general form and arrangement of this apparatus, and the

manner of applying it to thermal researches, are represented in *figs.* 281, 282, 283, and 284.

Upon the stand S is placed the source of heat which is submitted to experiment. Those which M. Melloni selected were a lamp L, with a concave reflector *t*; a spiral wire of platinum H (*fig.* 282.), rendered incandescent by the flame of a spirit-lamp; a plate of copper I (*fig.* 283.), blackened with smoke, and raised to the temperature of 700° by a spirit-lamp; and, in fine, a cubical canister K (*fig.* 284.), similar to those used by Leslie.

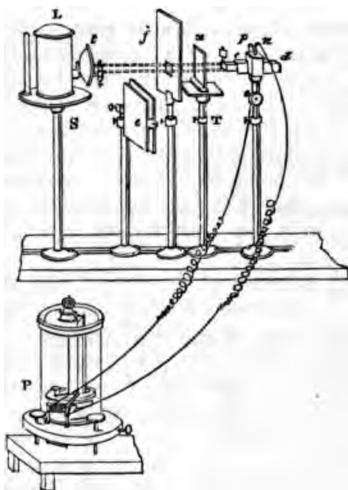


Fig. 281.

On the stand T was placed the body *x*, through which the rays of heat were to be transmitted, and which was formed into a thin plate. An athermanous screen *f* was interposed, having in it an aperture to limit the pencil of rays transmitted to *x*. Another athermanous screen was placed at *c*, movable upon a joint by which the pencil proceeding from the lamp could be intercepted or transmitted at pleasure.

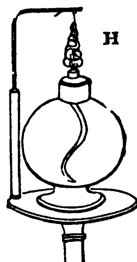


Fig. 282.

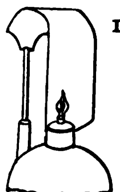


Fig. 283.

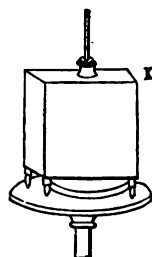


Fig. 284.

The thermo-voltaic pile was placed at *p*, having one end presented to the thermal pencil, and movable in a case fitting it, in which it was capable of sliding. Its poles *p* and *n* were connected by conducting wires with the galvanometer P, the needle of which

indicated by its deflection the intensity of the heat by which the pile was affected.

578. The series of experiments made with this apparatus gave the remarkable, and in many respects unexpected, results which we shall now briefly state.

The only substance found to be perfectly diathermanous was rock salt. Plates of this crystal transmit nearly all the heat which enters them, no matter from what source. Of the incident rays 7·7 per cent. are reflected from both surfaces of the plate, and the whole of the remaining 92·3 per cent. are transmitted. There is no absorption.

Bodies in general are less athermanous the higher the temperature of the radiator.

579. Media are not diathermanous in proportion as they are transparent. On the contrary, certain media which are nearly opaque are highly diathermanous, while others which are highly transparent are nearly athermanous. Thus, black glass and plates of smoked quartz, so opaque that the disc of the sun in the meridian is barely visible through them, are much more diathermanous than plates of alum, which are very transparent; and plates of quartz smoked to opacity are more diathermanous than when clean and transparent. In like manner, black glass is more diathermanous than colourless glass.

580. The thermal pencil is composed of rays, some of which are absorbed, and others transmitted by certain media. This effect is altogether analogous to that which is produced by coloured media on light. If a pencil of solar light be incident upon red glass, the red rays alone will be transmitted, those of the other colours being absorbed; but if the red light transmitted through such a plate be received upon a second red plate, there will be no further absorption; at least, so far as depends on the colour of the light. In like manner, when a thermal pencil enters certain diathermanous media, a part of its rays are intercepted, others being transmitted. If these last be received upon another plate of the same diathermanous substance, they will pass freely through it without further absorption.

It is therefore inferred that such a medium decomposes by absorption the thermal pencil, in the same manner as a coloured transparent medium decomposes by absorption a pencil of white light. This inference is confirmed by the fact that different partially diathermanous media absorb different constituents of the thermal pencil. Thus we may cause its entire absorption by causing it successively to pass through two media, each of which absorbs the rays transmissible by the other.

This is also analogous to the effects of coloured transparent media upon luminous pencils. If a pencil of solar light be successively incident upon two plates, one of red and the other of the complementary tint of bluish-green, it will be wholly absorbed, the second plate absorbing all the rays transmitted by the first.

581. The partial absorption produced by such imperfectly diathermanous media is not effected at the surface. The rays are absorbed gradually as they pass through the medium. This, however, is not continual. All absorption ceases after they have passed through a certain thickness, and the rays transmitted by a plate of that thickness would, in passing through a second plate of the same substance, undergo no further absorption.

Glass and rock crystal are each partially diathermanous, the thermal rays transmitted and absorbed, however, being different. If a thermal pencil pass through a plate of glass of a certain thickness, a part of the rays composing it will be absorbed. If the rays transmitted be received on another similar plate of glass, they will be all, or nearly all, transmitted, no further absorption taking place. But if these rays thus transmitted by the glass be received upon a plate of rock crystal of sufficient thickness, a portion of them will be absorbed. Now if the glass and the rock crystal had each the power of absorbing the rays transmitted by the other, their combination would be absolutely athermanous, just as two plates of coloured glass would be opaque, if each transmitted only the colours complementary to those transmitted by the other.

582. **Diathermanism.** — It appears from the researches of Melloni, that the physical conditions which render bodies more or less diathermanous have no connection with those which affect their transparency. Water is one of the least diathermanous substances, although its transparency is so nearly perfect. If, therefore, it be desired to transmit light without heat, or with greatly diminished heat, it is only necessary to let the rays pass through water, by which they will be strained of a great part of their heat.

If the quantity of radiant heat transmitted through air be expressed by 100, the following numbers will express the quantity transmitted through an equal thickness of the substances named below: —

Air	100	Rape oil	30
Rock salt (transparent)	92	Tourmaline (green)	27
Flint glass	67	Sulphuric ether	21
Bisulphuret of carbon	63	Gypsum	20
Calcareous spar (transparent)	62	Sulphuric acid	17
Rock crystal	62	Nitric acid	15
Topaz, brown	57	Alcohol	15
Crown glass	49	Alum, crystals	12
Oil of turpentine	31	Water	11

It appears, therefore, that of all solid bodies rock salt is the most diathermanous, and alum the least so. Of all liquids, bisulphuret of carbon is the most, and water the least, diathermanous.

It is evident from this table, that bodies are not diathermanous and transparent in the same degree. Rock salt is less transparent but more diathermanous than glass.

It has been found that the power of thermal rays to penetrate an imperfectly diathermanous body is augmented by raising the temperature of the radiator. This is rendered very apparent in the case of glass, which is much more diathermanous to heat radiated by a body at a very high, than by one at a moderate temperature. This may explain the fact that bodies in general are more diathermanous to solar light than to light proceeding from artificial sources.

It is found that heat radiated by bodies which are in a state of ignition or incandescence penetrate diathermanous media more freely than those radiated by bodies which are not luminous. This is in accordance with the general principle already stated, that thermal rays penetrate diathermanous bodies more easily the higher is the temperature of the radiator.

Experiments on the thermal analysis of solar light were made by transmitting a pencil of solar light, either obtained directly or by reflection, through the aperture in the screen *f*, *fig.* 281.

583. **Polarisation of heat.** — Experiments on the refraction, reflection, and polarisation of heat were made, by placing on the stand T, *fig.* 281., prisms of various materials, reflecting surfaces, polariscopes, or double refracting crystals. The thermoscopic apparatus was in each case placed in such a position as to receive the deflected thermal pencil.

In this manner pencils of heat proceeding from various sources were submitted to the same effects of refraction, reflection, and polarisation as are explained in "Optics" with respect to light, and analogous results were obtained; the thermal rays being subject to the same general laws of reflection and refraction as prevail in relation to luminous rays.

584. The general principles regulating the radiation, absorption reflection, and transmission of heat, which have been here stated, serve to explain and illustrate various experimental facts and natural phenomena, as will appear from what follows: —

If two concave parabolic reflectors, shown in *fig.* 285., are so placed that their axes shall be in the same direction, their concavities being presented one to the other, any radiator of heat placed in the focus of either will produce a corresponding effect

upon a thermometer placed in the focus of the other, the rays of heat issuing from the radiating body being twice reflected and collected in the focus of the second reflector.

585. Let R and R′, *fig.* 285., be two such reflectors. If lighted charcoal be placed in the focus F of one, it will ignite amadou or any other easily inflammable substance in the other, even though the distance between the reflectors be twenty or thirty feet.

If a sensitive thermometer, such as the differential thermometer (344.), be placed at F′, it will show an increase or diminution of temperature, according as a hot or cold body is placed at F. If a small globe filled with hot water be placed there, an increase will

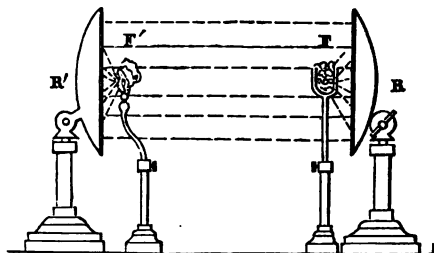


Fig. 285.

be indicated; and if the globe be filled with snow or with a freezing mixture, a decrease will be manifested. A perspective view of the apparatus is given in *fig.* 286., where D and E are the reflectors, C the source of heat placed in the focus of D, and F the object affected by the reflected rays in the focus of E.

586. Vessels intended to hold liquids at a higher temperature than that of the surrounding medium, should be constructed of materials which are bad radiators. Thus tea-urns, tea-pots, &c., are best adapted for their purpose when made of polished metal, and worst when of black porcelain. A tea-kettle keeps water hot more effectually if clean and polished, than if covered with the black of soot and smoke. Polished fire-irons remain longer before a hot fire without being heated than rough unpolished ones.

587. A polished stove is a bad radiator; one with a rough and blackened surface a good radiator The latter is therefore better adapted for warming an apartment than the former.

588. The helmet and cuirass worn by cavalry is a cooler dress than might be imagined, the polished metal being a good reflector of heat, and throwing off the solar rays.

589. When the external air, which generally happens, is at a

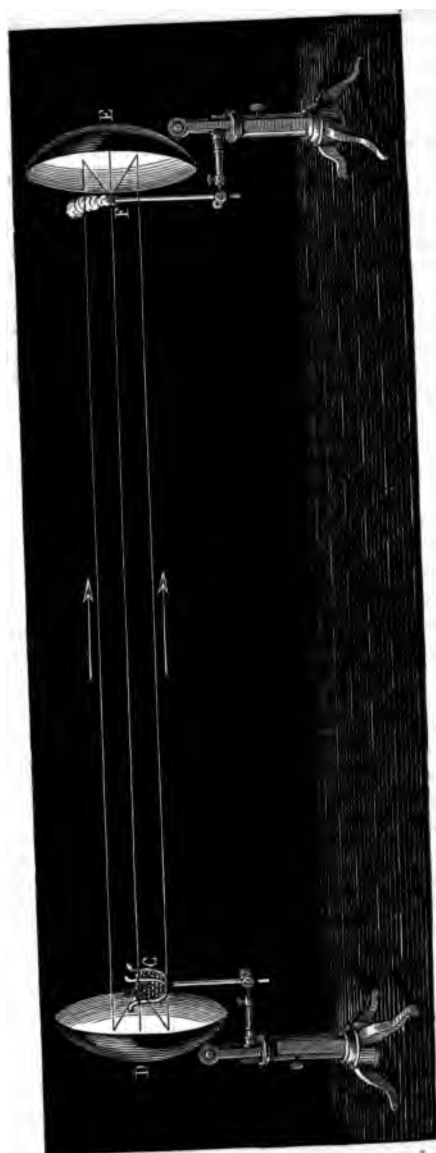


Fig. 286.

lower temperature than the air included in the room, it will be observed that a deposition of moisture will be formed upon the inner surface of the panes of glass in the windows. This is produced by the vapour suspended in the atmosphere of the room being condensed by the cold surface of the glass. If the external air in this case be at a temperature below 32°, the deposition on the inner surface of the glass will be congealed, and a rough coating of ice will be exhibited upon it.

Let two small pieces of tinfoil be fixed, one upon a part of the external surface of one of the panes, and the other upon the internal surface of another pane, in the evening; it will be found in the morning that that part of the internal surface of the pane upon which is placed the external foil will be nearly free from ice, while the surface of the internal foil will be more thickly covered with ice than the parts of the inner surface of the glass which are not covered with foil: these effects are easily explained by radiation. When the tinfoil is placed on the external surface, it reflects the heat which strikes on that surface and protects that part of the surface which is covered from its action. The heat radiated from the objects in the room striking on the inner surface of the glass penetrates it, and encountering the foil attached to the exterior surface, is reflected by it through the glass, and its escape into the external atmosphere is intercepted; the portion of glass, therefore, opposite to the tinfoil, is subject to the action of the heat radiated from the chamber, but protected from the action of the external heat. The temperature of that part of the glass is therefore less depressed by the external atmosphere than the temperature of those parts which are not covered by tinfoil. Now glass being a bad conductor of heat, the temperature of that part opposite to the external foil does not immediately affect the remainder of the pane, and consequently we find that, while the remainder of the interior surface of the pane is thickly covered with ice, the portion opposite the tinfoil is comparatively free from it. On the contrary, when the tinfoil is applied on the internal surface, it reflects perfectly the heat radiated from the objects in the room, while it admits through the dimensions of the glass the heat proceeding from the external atmosphere. The portion of the glass, therefore, covered by the tinfoil, becomes colder than any other part of the pane, and the tinfoil itself partakes of this temperature, which is not raised by the effect of the radiation of objects in the room, because the tinfoil itself is a good reflector and a bad absorber. Hence the tinfoil presents a colder surface to the atmosphere in the room than any other part of the surface of the pane, and consequently receives a more abundant deposition of ice.

590. A clear unclouded sky in the absence of the sun radiates but little heat towards the earth; consequently, if good radiators be exposed to such an aspect, they must suffer a fall of temperature, since they lose more by radiation than they receive.

Let a glass cup, for example, be placed in a silver basin, and exposed during a cold night to a clear sky; it will be found in the morning that a copious deposition of moisture will have been made on the glass, from which the silver vessel is perfectly free. Reversing the experiment, let a silver cup be placed in a glass basin, and similar results will ensue, the basin being perfectly covered with moisture, from which the cup is free. This is easily explained: the metal, being a bad radiator of heat, preserves its temperature; the glass, being a good radiator of heat, loses by radiation much more than it receives, and consequently its temperature falls, and it condenses the vapour in the air around it.

The result of experiments of this kind supplied Dr. Wells with his celebrated theory, by which he explained the phenomenon of dew.

According to what has been explained, it appears that the objects which are good radiators, exposed to a clear sky at night, will become colder than the surrounding atmosphere, and will consequently condense the water suspended in the air around them; while objects which are bad radiators will not do this. Grass, foliage, and other products of vegetation are in general good radiators. The vegetation, therefore, which covers the surface of the ground in an open country on a clear night will receive a deposition of moisture from the atmosphere; while the objects which are less perfect radiators, such as earth, stones, &c., do not in general receive such depositions. In the close and sheltered streets of cities the deposition of dew is rarely observed, because there the objects are exposed to reciprocal radiation, and an interchange of heat takes place which maintains their temperature.

The effect of the radiation of foliage is strikingly manifested by the following example: — Of two thermometers, one laid among leaves and grass, and the other suspended at some height above them, the latter will be observed to fall at night many degrees below the former.

591. In a cloudy night dew is not deposited, because in this case, although vegetation radiates as perfectly as before, the clouds also radiate, and an interchange of heat takes place between them and the surface of the earth, by which the fall of temperature producing dew is prevented.

592. **Artificial ice.** — Artificial ice is sometimes produced in hot climates by the following process: — A position is selected, not exposed to the radiation of surrounding objects, and a quantity of dry straw is spread on the ground, on which pans of porous earthenware are disposed in which the water to be cooled is placed. The water radiates heat to the firmament, and receives no heat in return. The straw upon which the vessels are placed, being a bad conductor, intercepts the heat, which would otherwise be imparted to the water in the vessels from the earth. The porous nature of the pans also allowing a portion of the water to penetrate them, produces a rapid evaporation, by which a considerable quantity of the heat of the water is carried off in a latent state by the vapour. Heat is thus dismissed at once by evaporation and radiation, and the temperature of the water in the pans is diminished until it attains the freezing point. In the morning the water is found frozen, and is collected and placed in cellars surrounded with straw or other bad conductors, which prevents its liquefaction.

CHAP. IX.

COMBUSTION.

593. It has been already explained that when two substances enter into chemical combination, so as to form a new compound, heat is generally either developed or absorbed; so that, although the components before their union have the same temperature, the temperature of the compound which results will be generally above or below this common temperature, and sometimes considerably so.

594. If no change in the state of aggregation of the constituents is produced by their union, this phenomenon is explained by the specific heat of the compound being less or greater than that of the components, according as the temperature of the compound is greater or less. If greater, it is because, the specific heat being less, the actual quantity of heat contained in the compound gives it a higher temperature; if less, because it gives it a lower temperature.

595. If the state of aggregation of either or both of the components be changed, heat which was latent becomes sensible, and raises the temperature of the compound; or heat which was sensible becomes latent, and lowers it. Thus, when a solid mixed

with a liquid is dissolved in it, the solid in liquefying absorbs and renders latent the same quantity of heat which would have been necessary to melt it. This heat, being abstracted from the sensible heat of the compound, lowers the temperature. This phenomenon has been already noticed in the case of freezing mixtures.

596. **Combustion.** — But of all the cases in which heat is developed by chemical combination, the most important are those in which combustion is produced. When the quantity of heat suddenly developed by the chemical combination of two bodies renders the compound luminous, the bodies are said to burn, and the phenomenon is called *combustion*. If the product of the combination be solid it is called *fire;* if gaseous, *flame*.

597. Flame, therefore, is gas rendered *white hot* by the excessive heat developed in the combination which produces it.

598. It happens that, among the infinite variety of substances whose combination is productive of this class of phenomena, one of the two combining bodies is almost invariably oxygen gas. A few other substances, such as chlorine, bromine, and iodine, produce similar effects; but in all ordinary cases of combustion, and universally where that effect is resorted to as a source of artificial heat, one of the combining substances is oxygen gas.

On this account this gas has been called a *supporter of combustion.*

599. The substances which, combining with it, produce the phenomenon of combustion, are called *combustibles.*

The class of combustible substances which are commonly used for the production of artificial heat is called *fuel.* Such, for example, are pit coal, charcoal, and wood.

Another class of combustibles is used for the production of artificial light: such, for example, are oil, wax, and the gas extracted from certain sorts of pit coal, from oil, and from certain sorts of wood, such as the pitch pine.

The principal constituents of all these combustibles, whether used for the production of heat or light, are those denominated by chemists *carbon* and *hydrogen.*

600. **Carbon.** — This is the name given to charcoal when it is absolutely pure, which it never is as it is obtained by the ordinary industrial processes. It is in that state combined with various heterogeneous and incombustible substances. In the laboratories of chemists it is separated from these, and obtained in a state of perfect purity, being there distinguished from the charcoal of commerce by the name *carbon.*

Carbon, having never been resolved by any chemical agent into other constituents, is classed in chemistry as a simple and elemen-

tary body, which enters largely into the composition of a numerous class of bodies which are found in nature, or produced in the processes of industry, the sciences, and the arts.

601. A quantity of charcoal being placed in a furnace through which a draught of air is maintained, if a part of it be heated to redness, the entire mass will soon become incandescent, and will emit a reddish light, which will be whiter as the air is passed through it more briskly, and will emit considerable heat. The charcoal will gradually decrease in quantity, and at length will disappear altogether from the furnace, under which a small portion of ashes consisting of incombustible matter will remain. If the charcoal had been pure — that is, if it had been carbon — it would have altogether disappeared, no ash whatever remaining.

602. This phenomenon is an example of combustion. The heat and light developed during the process here described are commonly called fire.

To comprehend what takes place in this process, we must consider that, as the air passes through the charcoal, the oxygen gas, which forms one fifth part of it, enters into combination with the pure carbon. A compound is thus formed consisting of carbon and oxygen. The formation of this compound is attended with so great a production of heat, that not only the compound itself, but the charcoal, from which it is evolved, is raised to a very elevated temperature.

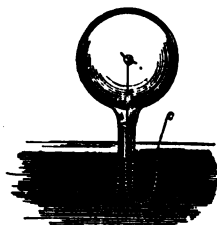
The compound thus produced is a gas called carbonic acid.

The air which enters the furnace being a mixture of azote and oxygen, that which rises from it after the combustion has been produced is a mixture of azote and carbonic acid; the azote having passed through the furnace without suffering other change than an increase of temperature, while the oxygen has been converted into highly heated carbonic acid.

Several questions, however, arise out of this explanation. How is it known that such combination really takes place between the carbon and oxygen? If it do, in what proportion do they combine? How does it appear that the azote, which forms four fifths of the air which passes through the furnace issues unaltered?

603. To supply satisfactory answers to these questions, it is only necessary to bring the two constituents of common air separately into the presence of carbon under the conditions necessary to favour combination, and to ascertain their weights before and after the development of the phenomena.

Let a glass flask, containing sixteen grains of oxygen gas, be inverted over mercury, as represented in *fig.* 287., and let a piece of carbon weighing more than six grains, supported in a platinum spoon, be introduced into it by means of a piece of


Fig 287.

bent platinum wire; let the sun's rays, concentrated by means of a burning-glass, be then directed upon the carbon through the glass flask. The carbon will be ignited by the solar heat, and will burn in the oxygen with great splendour. When the combustion has ceased and the gas contained in the flask has cooled, it will be found that the mercury in the neck of the flask will stand at exactly the same elevation as it did before the combustion. The gas contained in the flask has therefore the same volume as before; nevertheless it is easy to show that it is by no means the same gas.

In the first place, if it be weighed, it will be found to weigh 22 instead of 16 grains; and if the unburned residue of the carbon be weighed, its weight will be found to be 6 grains less than it was before the experiment. The inference is, that 6 grains of the carbon have combined with the 16 grains of the oxygen previously contained in the flask, but that in thus combining, the carbon has not made any change in the volume of the gas.

If the gas contained in the flask be examined by the usual tests, it will immediately appear that it is no longer oxygen. No combustible will burn in it, and it will not support life by respiration. In fine, it will be found to be identical with the noxious gas called choke-damp, and to possess all the chemical characters of the gas called *carbonic acid*.

If the same flask, similarly filled with nitrogen gas or azote be submitted to a like experiment, the result will not be the same. The solar rays concentrated on the charcoal will still render it red hot, but it will not burn nor undergo any other change. On removing the focus of solar rays from it, it will become gradually cool, and when removed from the flask will have the same weight as when introduced into it. The azote which fills the flask will also be found to be unaltered.

It follows, therefore, that the *fire* produced when carbon burns in common air is nothing more than the heat and light developed in the formation of carbonic acid, by the combination of the carbon with the oxygen of the surrounding air, and that these substances combine in the proportion of 6 parts by weight of carbon to 16 of oxygen.*

604. **Hydrogen.** — Like carbon, this is classed as a simple and

* More precisely 6·04 or 6·12 of carbon to 16 of oxygen.

elementary substance; and also, like carbon, enters largely into the composition of a numerous class of bodies. Hydrogen combines with oxygen in the proportion of 1 part by weight of the former to 8 of the latter to form water, and if the combination be formed in a pure or nearly pure atmosphere of the gases it is instantaneous, and accompanied by an explosion. If, however, the combination take place, as it may, in common air, the phenomena will be very different.

If pure hydrogen, compressed in a bladder or other reservoir, be allowed to issue from a small aperture, a light applied to it will cause it to be inflamed. It burns tranquilly without explosion, producing a pale yellowish flame and very feeble light, but intense heat. This is the effect attending the gradual and continual combination of the hydrogen, as it escapes from the aperture, with the oxygen of the surrounding air. It may be asked why the hydrogen issuing from the aperture does not combine with the oxygen of the air without the application of a flame to it? And also why, being once inflamed by the application of such a body, its continued application becomes unnecessary?

These questions are easily resolved. The hydrogen gas has an affinity or attraction for oxygen, which is not strong enough to cause their combination at common temperatures; but when the temperature of the hydrogen is greatly elevated, its attraction for the oxygen becomes so exalted, that it enters into instant and spontaneous combination with it. Now by applying the flame of a lamp or candle, or any other burning body, to the jet of hydrogen, its temperature becomes so greatly raised, and its attraction for oxygen consequently so exalted, that it enters directly into combination with the oxygen of the air which is in immediate contact with it at the moment.

605. But it is also asked how the continuance of the combination and the consequent maintenance of the flame takes place — the candle or lamp which produced its commencement being withdrawn? This is explained by the great quantity of heat produced by the combination of the hydrogen with the oxygen. The commencement of the combination being produced by the candle or lamp, the hydrogen and oxygen themselves, in the act of combining, develop an intense heat, and the succeeding portion of hydrogen gas, being in contact with them, becomes heated, and combines, like the former, with a fresh portion of oxygen. In the same manner, the heat developed by these being shared by the succeeding portion of gas, a further combination and development of heat takes place, and so on. Thus, the combustion being once commenced, the heat necessary for its maintenance and continuance is developed in the process itself, which accordingly goes on

without the necessity of being again kindled by the application of any flame.

The continuance of the combustion of carbon, whether in pure oxygen gas or in common air, is explained in the same manner.

606. The combustion of carbon differs from that of hydrogen in this, that the former takes place without the production of *flame*. The charcoal being heated to redness, and still in the solid form, enters directly into combination with the oxygen of the surrounding air, and the carbonic acid which is formed, being a gas which is not luminous nor visible, the carbon disappears. But in the case of hydrogen, the heat produced by the combustion is so intense as to render the gas itself luminous, just as intense heat will render a mass of iron red hot or white hot. When gas becomes thus luminous, it is called *flame*.

607. Flame, therefore, must be understood to be nothing more than matter in the aeriform, gaseous, or vaporous state, rendered so intensely hot as to become incandescent, and to emit light, just as would a bar of iron taken from a furnace.

608. It is easy to show that the product of the combustion of hydrogen is the vapour of water, which, by exposure to cold, can be reduced to the liquid state.

If a glass jar be held over a jet of inflamed hydrogen, as represented in *fig.* 288., the aqueous vapour formed by the combination of the hydrogen with the oxygen of the surrounding air will be condensed upon the inside of the jar, and will appear first as a cloudy dew upon it, and, as the process is continued, it will increase in quantity, and, trickling down the side of the jar, may be received in drops by a dish placed beneath it.

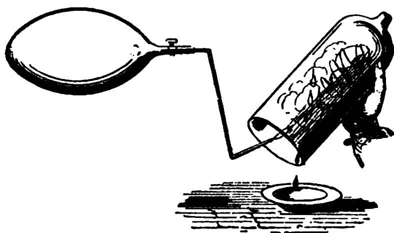


Fig. 288.

As we have stated above, the principal constituents of every species of combustible, whether used for heating or lighting, are carbon and hydrogen, and the products of their combustion are

therefore carbonic acid and water, the latter being evolved in the form of vapour.

609. It happens, however, rarely that the hydrogen is evolved in the pure state. It is more generally combined with a certain dose of carbon, forming a compound gas called *carburetted hydrogen.* This gas burns with a much whiter and more luminous flame than that of pure hydrogen, and it is therefore much better fitted for the purpose of illumination.

That the flame owes its whiteness and illuminating power to the carbon with which the gas is charged, is proved by the fact that the more carbon the gas is charged with, the whiter and brighter is the flame.

There are two sorts of carburetted hydrogen, one of which contains twice as much carbon as the other: the one called light carburetted or proto-carburetted hydrogen, and the other heavy carburetted or bi-carburetted hydrogen, or olefiant gas.

In light carburetted hydrogen 6 parts, or, more exactly, 6·12 parts by weight of carbon, are combined with 2 of hydrogen, and heavy carburetted hydrogen contains twice that proportion of carbon.

Light carburetted hydrogen is a little more than half the weight of its own bulk of common air. When pure, it has no odour; and it burns with a yellowish flame much more luminous than that of pure hydrogen. Like pure hydrogen, it forms a highly explosive mixture when combined in a certain proportion with common air, or, more properly, with the oxygen of common air, since the azote has no influence on the phenomenon.

610. It is this gas which, under the name of *fire-damp*, produces occasionally such disastrous explosions in coal mines. Being contained in large quantities in the fissures and interstices of the seams of coal, it issues from them in the workings of the mines, and being one half lighter than common air, it first collects at the top of the working. After a certain time, by a common property of all gases, it mixes with the air, and attains occasionally that proportion which renders it explosive. If a light be brought into it in this state, an explosion takes place, producing those destructive consequences to the operatives who happen at the moment to be present, with the details of which the public has been so often rendered familiar.

611. This gas is also that which, over marshy ground and stagnant pools, produces the appearance called *Will o' the wisp*, *Jack o' lanthorn*, or ignis fatuus. The gas is produced by the decomposition of vegetable and animal matter, and, rising from the ground or from the water, is spontaneously ignited.

It is easy to verify this by actually collecting the gas from any

stagnant pool. For this purpose, take a common funnel used for decanting liquors, and a bottle or beer glass; immerse the latter in the water, and when it is filled, invert it under the water and raise it above the surface, keeping the mouth under the water. Then bring the inverted funnel under its mouth, the neck entering the bottle or glass; agitate the funnel, and the gas will rise from the water in bubbles, and will collect in the upper part of the bottle or glass.



Fig. 289.

The manner of performing this experiment is shown in *fig.* 289.

When the gas is thus collected, its inflammable nature may be ascertained by applying a light to it as it issues from the bottle.

612. Heavy carburetted hydrogen burns with a much whiter and more luminous flame. Its weight is very nearly equal to that of common air, and, therefore, nearly double that of the light carburetted hydrogen; hence it has acquired the epithet "heavy."

The products of the combustion of both sorts of carburetted hydrogen are carbonic acid and water, the former proceeding from the combination of the carbon, and the latter from that of the hydrogen with the oxygen of the air.

These points being understood it will be easy to render intelligible the effects which are developed in all ordinary cases in which *fire* or *combustion* takes place.

613. The species of combustible used as fuel with which we are most familiar in this country is *pit coal.*

This mineral, exclusive of some extraneous and incombustible ingredients which it contains in very small proportions, consists of carbon and carburetted hydrogen of both kinds.

The proportion of carbon varies in different sorts of coal from 80 to 90 per cent., the hydrogen varying from 3 to 6 per cent., and the remainder consisting of oxygen and azote.

In the heavy coal of Wales, called anthracite, the proportion of carbon is above 90 per cent., while that of the hydrogenous gases is only 3 or 4 per cent. In the bituminous coal of Northumberland the proportion of carbon is about 87 per cent., and that of hydrogen from 5 to 6 per cent.

614. When a fire composed of such fuel is properly kindled and supplied with a draught of air necessary to sustain the combustion, the carbon will continue to combine with its proper proportion of oxygen, producing the corresponding quantity of heated

carbonic acid, and rendering the solid part of the fuel red and luminous; and the hydrogenous gases will at the same time combine with their respective proportions of oxygen, producing carbonic acid and watery vapour, and rendering the gases as they issue from the fuel luminous, or, what is the same, converting them into flame.

The flame will be faintly luminous and bluish if any part of the gases be pure hydrogen; it will be yellowish and a little more luminous if they be light carburetted hydrogen; and it will be very white and very luminous if they be heavy carburetted hydrogen.

Thus all the phenomena exhibited by a common coal fire, — the red unflaming fuel, — the faint blue flames occasionally seen, — and, in fine, the white brilliant flame which most commonly issues from the fissures of the coal, are severally explained and accounted for.

615. It has been shown that in combustion 6 parts, by weight, of carbon combine with 16 of oxygen, or, what is the same, 1 part with 2⅔. It has also been shown that in the combustion of hydrogen, 1 part by weight of that gas combines with 8 of oxygen. Now by these simple numerical data may be easily explained the effects of a common coal fire upon the air which feeds and sustains it.

616. It is thus found that in burning 10 lb. of coal the oxygen contained in 1551 cubic feet of air is altogether absorbed.

To keep the atmosphere of a room in which a fire of such coal is burned fresh and pure, it would be, therefore, necessary to supply fresh air at the rate of 155 cubic feet for every pound of coal which is burned.*

617. Wood is a combustible generally used for the production of artificial heat in countries where coal is not so cheap and abundant as in England. This fuel, like coal, consists principally of carbon and hydrogen in various proportions, according to the sort of wood. All kinds of wood contain also a proportion of oxygen, as a constituent, much greater than is found in coal.

Wood, when green, contains a considerable proportion of water. In the combustion of such wood a large proportion of the heat developed is absorbed in the evaporation of this water, and is, therefore, lost for heating purposes. Wood used as fuel should, therefore, be kept until this water, or the chief part of it, has been evaporated. For the same reason, wood kept for fuel should be as little exposed to moisture or damp as possible.

* In the preceding explanation we have omitted to take into account the effect of a small proportion of oxygen which enters into the composition of coal. This, however, is so insignificant that it would be needless to complicate the calculation by introducing it.

618. All fatty, oily, and waxy substances are combustible, whether in the liquid or solid state. They consist of the same constituents as coal and wood, but combined somewhat differently and in different proportions. Most substances of this class, burning with a flame of more or less brilliancy, are used for the purposes of artificial illumination.

Whale, sperm, olive, and cocoa-nut oils, wax, spermaceti, and tallow are examples of this class of combustibles.

619. Whatever be the sort of combustible, or whatever be the purpose to which it is applied, whether for heating or lighting, it will be evident from the explanations which have been here given, that the combustion cannot be maintained with the necessary activity unless expedients be provided for the supply of the quantity of oxygen which must enter into combination with it.

620. The construction of grates, stoves, and chimneys is therefore designed to attain this end by causing such a volume of common air to pass through the fuel as is necessary and sufficient to combine with it. The more air which thus passes through the fuel, the more rapid and abundant will be the combination, and the more active and vivid the combustion.

The current of air which passes through a common grate is produced by the draught of the chimney. The column of air included in the chimney, being raised to a higher temperature than that of the external air, is rarefied and lighter, bulk for bulk, than the external air, and is proportionately more buoyant. It has, therefore, a tendency to ascend like that which oil would have in water. As it ascends the air from the room must rush in to fill its place. A part of this air will pass through the bottom and front of the grate, and a part will enter at the opening of the fire-place over the grate. This will be more easily understood by *fig.* 290. The front of the grate is A B, and the bottom B C, having the ash-pit below it. The opening over the grate is A I, and E F G H is the flue of the chimney. The ascensional force of the column of air in the flue is measured by the difference between its weight and that of an equal volume of the external air. The air which replaces that which ascends in the flue enters the bottom B C, the front B A of the grate and the opening A I above it, as indicated by the arrows. The former portions, passing through the burning fuel, supply to it the oxygen gas necessary to combine with it, and thus maintain the combustion. These portions, after passing through the interstices of the fuel, and after the oxygen, or a part of it, has combined with the fuel, issue from the top of the fuel, being then a mixture of azote, such portion of oxygen as may not have combined with the fuel, carbonic acid and aqueous vapour, the latter being

the products of the combination of the oxygen with the carbon and the hydrogen of the fuel.

All these gases, issuing from the burning fuel at a high temperature, and mixing with the cold air which enters the chimney through the opening A I, render the column of air in the flue so warm as to give it the buoyancy necessary to sustain the draught.

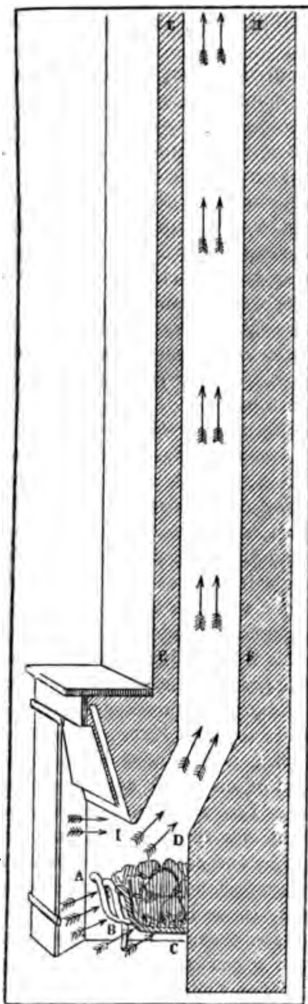


Fig. 290.

When the fire is first kindled in the grate, if the air in the chimney have the same temperature as the external air, it will have no buoyancy, and there will be no draught. In this case the chimney will generally be found to smoke. This inconvenience may be sometimes removed by opening the windows, so as to fill the room with air as cold as the external air, and therefore colder than the air in the chimney. If, however, this be found insufficient, the air in the flue may be warmed and the necessary draught produced by holding under the chimney any blazing combustible.

The draught through the grate may be greatly increased in intensity by stopping up, either partially or completely, the opening A I. By this expedient, all the air necessary to replace that which ascends in the chimney must pass through the fuel in the grate. If the magnitude of the opening be, for example, three times the magnitude of the front and bottom of the grate, four times as much air will thus pass through the fuel as would pass through it when the opening

A I is not closed, supposing the draught in the chimney to be the same in both cases.

But, in fact, the draught in the chimney will be greatly augmented by this process; for, so long as the opening A I is not closed, the air which fills the chimney will consist of a mixture of that which passes through the burning fuel, which is raised to a high temperature, and the much larger portion which passes into the chimney through the opening A I, and which, being cold, lowers the temperature, and therefore diminishes the buoyancy of the air in the chimney. But when all the air which passes through A I, by closing that opening, is made to pass through the burning fuel, it is raised to a high temperature, which, not being lowered by admixture with any air not passing through the fuel, fills the chimney with air raised to a very elevated temperature, and which therefore produces in the chimney a much stronger upward current.

Thus the effect of closing the opening A I is to stimulate the fire, not only by causing to pass through it all the air which previously entered the opening A I, but also by augmenting the draught in the chimney.

621. From what has been explained above, it will be perceived that an open fire-place, such as is represented in *fig.* 290., serves the double purpose of warming and ventilating.

All the air which enters the chimney, whether it passes through the grate or through the opening above the grate, must be replaced by an equal volume of fresh air from without, which must find its way through the interstices of doors and windows, or through other openings provided expressly for its admission. That part of the air which passes through the grate subserves the double purpose of warming and ventilation. It warms by stimulating and maintaining the combustion of the fuel, and it ventilates by leaving in the room a void into which an equal volume of fresh air must enter. That portion of air which enters the chimney through the opening above the grate has no effect, direct or indirect, in warming, but its effect in ventilating is just so much greater than that of the air which passes through the grate, as the magnitude of the opening above the grate is greater than the magnitude of the spaces between the bars in the front and bottom of the grate.

The necessity for ventilation is so much the greater as the room is smaller and lower, and as the causes of the pollution of its air are more numerous and active. The air of a room is deprived of its oxygen, and rendered unfit for respiration by several causes. Each person who is present in the room absorbs oxygen by respiration. It is calculated that an adult of average size absorbs about a cubic foot of oxygen per hour by respiration, and conse-

quently renders five cubic feet of air unfit for breathing. It is also computed that two wax or sperm candles absorb as much oxygen as an adult. It follows, therefore, that to keep the air of a room pure, five cubic feet for every person, and two and a half cubic feet for every candle in the room should pass per hour into the chimney, or through some other opening, and an equal volume of fresh air should be admitted.

622. Plants give out oxygen by day, but absorb it by night. Their presence in a room by day is therefore innocuous, but at night they have the effect of polluting the air, and should never be admitted except where there are ample means of ventilation.

623. A crowded room, illuminated with many candles and lamps, and, as generally happens, without a fire, soon becomes filled with air in which there is a deficient proportion of oxygen and a corresponding volume of carbonic acid, unless means be provided, which is rarely the case, for other ventilation besides that of the chimney. Hence it arises that persons of delicate habits, especially those whose lungs are defective, in such a room, soon become sensible of general uneasiness, and are often affected with headache.

624. The manner in which the flame of lamps and candles is produced and maintained will require some explanation.

When a candle is lighted, the heat developed at the extremity of the wick melts the wax or tallow immediately below it, and thus liquefied, it is drawn up through the interstices of the wick by the force called capillary attraction. When it comes in contact with the flame, it boils, and is converted into vapour, which rises over the wick. This vapour having a very high temperature, and exercising a strong attraction for the oxygen of the surrounding air, enters into combination with it, and becoming luminous, forms the flame around and above the wick. Within the flame arises a constant current of the vapour of the combustible, and outside it currents of air carry to the surface of the flame the oxygen which produces the combustion and the light. The combustible vapour and the oxygen meeting at the surface of the flame, there enter into combination, and the vapour burns. Within the flame no combustion takes place, and no light is produced.

In *fig.* 291. the wick and flame are represented. Within the flame currents of combustible vapour proceed from the wick to all parts of the surface of the flame. The arrows at the sides of the flame outside its surface represent the currents of the surrounding air produced by the heat of the flame; the oxygen, being attracted by the intensely heated combustible vapour, approaches it, and, by combining with it, sustains the combustion and produces the light. The arrows above the flame indicate

the current of heated air, carbonic acid and aqueous vapour, the products of the combustion, which form an ascending column above the flame.

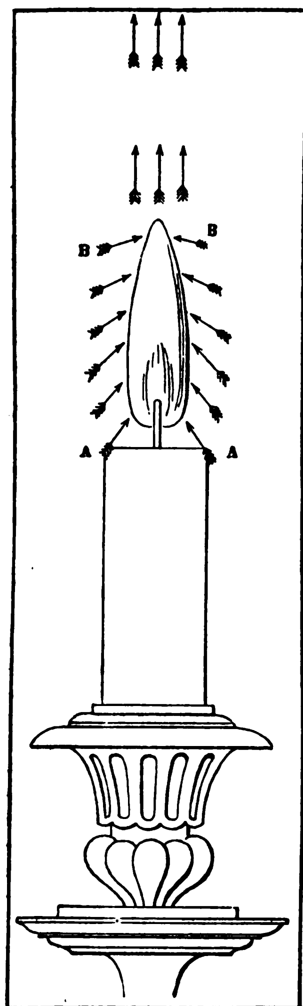


Fig. 291.

It will be apparent, from what has been here stated, that the luminous part of the flame is merely superficial. The vapour within the surface of the flame not having yet come into contact with the oxygen, and therefore not having entered into combustion, cannot be luminous. The flame, therefore, so far as relates to light, is hollow, or rather it is a column of combustible vapour, the surface being the only part which burns, and therefore the only part which is luminous. As this vapour ascends from the interior of the flame, it comes successively into contact with the oxygen of the air, is burnt, and becomes luminous, the column of light gradually contracting in diameter until it is reduced to a point. The flame thus tapers to a point until all the vapour produced by the boiling matter on the wick receives its due complement of oxygen, and passes off. It speedily loses that high temperature which renders it luminous, and the flame terminates.

625. In lamps of various construction, expedients are adopted to increase the magnitude of the luminous surface of the flame, and the intensity of the combustion. This is effected by modifying the form and magnitude of the wick, by feeding it with an abundant supply of oil, and by maintaining strong currents of air at all parts of its surface to sustain the combustion.

The most common form of wick used for lamps of strong illuminating power, is that of a hollow cylinder, varying from an inch to three inches in circumference. This wick, being attached at its base to a small thin ring of metal, is let down into the reservoir of oil, through a space included between two concentric tubes, one of which has a less diameter than the other, the space between them being a little wider than the thickness of the wick. The wick is from two and a half to three inches long, and descends through this space between the tubes to a certain depth. This space communicates with the reservoir of oil from which the oil is forced up either by the action of a pump worked by a main spring, through the intervention of wheelwork, as in the Carcel lamp, or by the more direct action of a strong spiral spring, as in the Moderator lamp, or by the pressure of oil contained in a reservoir above the level of the wick, as in the old English ring-lamp, called the Sinumbral lamp, and a variety of other forms constructed on the like principle.

The flame issuing from such a wick is obviously a hollow cylinder, and requires to be fed with air, both at its exterior and interior surfaces. A current of air in contact with the interior surface of the flame is maintained by carrying the lesser of the two tubes, between which the wick is included, down through the burner, and leaving it in communication with the external air. The exterior of the flame is exposed to the air, and produces currents by its own heat, in the same manner as the currents already described, surrounding the flame of a candle.

But in the case of lamps with cylindrical burners these currents, both exterior and interior, are greatly augmented in intensity by the addition of a cylindrical glass chimney of considerable height, the inner diameter of which a little exceeds the exterior diameter of the wick. This chimney being open at its base, and confining a column of air of its own height, acts upon the combustion of the lamp exactly as a common chimney acts on the combustion of fuel in a grate. The air which enters at the bottom, between this chimney and the burner, rises in a cylindrical current around the exterior of the wick, and passing in contact with the exterior surface of the combustible vapour proceeding from the oil, ignites it at that surface. The column of air which ascends at the same time through the inner tube, passing in contact with the inner surface of the vapour, ignites it in like manner. In this manner, a thin cylinder of oily vapour rising from the wick is kept in a state of vivid and constant combustion, both on its interior and exterior surfaces.

The force of these currents, exterior and interior, depends on the buoyancy of the column of air included in the chimney, and

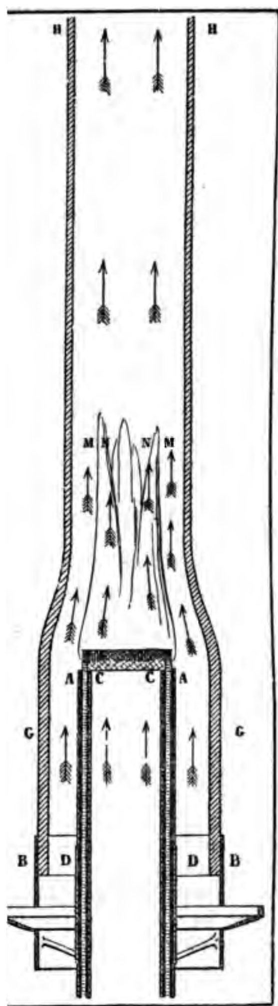


Fig. 292.

which also extends to a considerable height above it. The air, after passing the flame of the lamp, being at a very high temperature, the glass chimney itself becomes intensely hot. The column of air within the chimney being thus heated, it ascends to a considerable height above the chimney before it is cooled down to the temperature of the surrounding air. The force of the draught which maintains the currents around the flame is then determined by the difference between the weight of the column of air, extending from the base of the chimney to that height above it at which the temperature of the ascending column becomes equal to that of the external air, and the weight of an equal volume of the external air.

This explanation of the combustion of the oil in a cylindrical burner will be more clearly comprehended by reference to *fig.* 292., where C C represent the interior, and A A the exterior tube, between which the wick is included. The oil is forced up to the wick in the space between these tubes; G H, G H is the chimney, open at the base B B. The air ascends as indicated by the arrows between G H and D A, and passes in contact with the external surface of the flame, and it rises through the internal tube C C, passing in contact with the internal surface of the flame, as indicated by the arrows. The ndrical flame, ascending from the wick, is represented at C N, and the course of the ascending column in the chimney presented by arrows.

626. The temperature necessary to produce combustion is different for different substances; phosphorus combines with oxygen, and burns in the atmosphere if raised to 148°. Hydrogen gas will not burn till raised to incandescence. According to Sir H. Davy, the temperatures necessary to the combustion of the several combustibles here named are in the following order:—

1. Phosphorus.
2. Phosphoretted hydrogen.
3. Hydrogen and chlorine.
4. Sulphur.
5. Hydrogen and oxygen.
6. Olefiant gas.
7. Sulphuretted hydrogen.
8. Alcohol.
9. Wax.
10. Carbonic oxide.
11. Carburetted hydrogen.

627. If a jet of hydrogen gas be directed upon a small mass of spongy platinum, the metal will become incandescent, and will continue so as long as the gas acts upon it, without, however, suffering any permanent change.

An apparatus for producing an instantaneous light has been contrived on this principle:—By turning a stop-cock communicating with a small bottle in which the gas is generated in the usual way, the jet of gas is thrown upon a small cup containing the spongy metal, which, immediately becoming incandescent, is capable of lighting a match.

Some other metals, palladium, iridium, and rhodium, are susceptible of the same effect.

This effect has not been yet explained in a clear or satisfactory manner. See Turner's "Chemistry," by Liebig and Gregory, 8th edit. p. 542.

628. The determination of the quantity of heat evolved by different combustibles is a question not only of great scientific interest, but of considerable importance in the arts and manufactures. The mutual relation between the quantities of the combustible, the oxygen, and the heat developed, if accurately ascertained, could not fail to throw light, not only on the theory of combustion, but on the physics of heat in general. In the arts and manufactures, the due selection of combustible matter depends in a great degree upon the quantity of heat developed by a given weight in the process of combustion.

Nevertheless, there is no part of experimental physics in which less real progress has been made, and in which the process of investigation is attended with greater difficulties. Experiments were made on certain combustibles by Lavoisier and Laplace, by burning them in their calorimeter, and observing the quantity of ice dissolved by the heat which they evolved. Drs. Dalton and Crawford, Count Rumford and Despretz, as well as Sir H. Davy, made various experiments with a like object. It was not, however, until the subject was taken up by Dulong that any considerable progress in discovery was made. Unhappily, that eminent

erimental inquirer died before his researches were completed. :h valuable information has been collected from his unfinished ıoranda. The inquiry has since been resumed by MM. Favre Silbermann, and has been prosecuted with much zeal and :ess. The estimates which they have obtained of the quan- s of heat developed in the combustion of various substances are ıd to be in general accordance with those which appear to have ı obtained by Dulong, in the cases where they have operated he same combustible. Thus, in the case of hydrogen, the most ortant of the substances under inquiry, Dulong found the heat eloped to be expressed by 34601; while MM. Favre and Silber- .n estimated it at 34462, with relation to the same thermal unit.

29. In the following table is given the heat developed in the bustions of the substances named in the first column; the ·mal unit being the heat necessary to raise a weight of water, al to that of the combustible, one degree of the scale of Fahren- 's thermometer: —

Substances.	Formulæ.	Quantity of Heat given by 1° of Combustion.
, at 59° -	- - -	62031·6
om C to CO^{2}	- - -	14544·7
rom sugar, to CO^{2} -	- - -	14471·6
rom gas re- - - -	- - -	14485·1
natural, - - -	- - -	14060·7
from high No. 1. - -	- - -	14013·5
natural, - - -	- - -	14006·7
- - -	- - -	13986·2
from high No. 2. - -	- - -	13926·8
heated -	- - -	14181·7
om carbon, - - -	- - -	4324·9
h - -	$C^{2} H^{4}$	23513·4
.nt - -	$C^{4} H^{4}$	21344·0
ıe - -	$C^{10} H^{10}$	20683·8
- - -	$C^{20} H^{20}$	20346·3
- - -	$C^{22} H^{22}$	20278·8
- - -	$C^{32} H^{32}$	19941·3
ıe - -	$C^{40} H^{40}$	19671·3
phuric -	$HO^{2}+C^{8} H^{8}$	16248·6
eric - -	$HO^{2}+C^{20} H^{20}$	18338·4
rood - -	$HO^{2}+C^{2} H^{2}$	9542·7
- - -	$HO^{2}+C^{4} H^{4}$	12931·2
aleric - -	$HO^{2}+C^{10} H^{10}$	16125·5
:halic - -	$HO^{2}+C^{32} H^{32}$	19132·6
- - -	$C^{6} H^{6}+O^{2}$	13149·0
ethalic -	$C^{32} H^{32} O^{2}$	18616·0
stearic -	$C^{38} H^{38} O^{2}$	18892·8
of methylene	$C^{4} H^{4} O^{4}$	7555·3
,, ,,	$C^{6} H^{6} O^{4}$	9615·6
of alcohol -	$C^{6} H^{6} O^{4}$	9502·2
etic - -	$C^{8} H^{8} O^{4}$	11326·9
of methylene	$C^{10} H^{10} O^{4}$	12237·3
tyric - -	$C^{12} H^{12} O^{4}$	12763·6

Names of Substances.	Formulæ.	Quantity of Heat given by 1° of Combustion.
Valeriate of methylene	$C^{14} H^{14} O^{4}$	13276·1
,, ,, alcohol -	$C^{14} H^{14} O^{4}$	14102·8
Acetate of alcohol, valeric - - -	$C^{20} H^{20} O^{4}$	14348·2
Ether, valeramilic -	$C^{20} H^{20} O^{4}$	15378·5
Acid, formic - -	$O^{4}+C^{2} H^{2}$	3600·0
,, acetic - -	$O^{4}+C^{4} H^{4}$	6309·4
,, butyric - -	$O^{4}+C^{8} H^{8}$	10121·4
,, valeric - -	$O^{4}+C^{10} H^{10}$	11590·2
,, ethalic - -	$O^{4}+C^{32} H^{32}$	16956·0
,, stearic - -	$O^{4}+C^{38} H^{38}$	17676·0
,, phrenic - -	$C^{12} H^{6} O^{2}$	14116·1
Terebene - - -	$C^{20} H^{16}$	19193·4
Essence of turpentine	$C^{20} H^{16}$	19533·6
,, citron -	$C^{20} H^{16}$	19726·2
Sulphur, native melted	- - -	3998·0
Sulphur, at instant of crystallisation -	- - -	4065·1
Sulphur of carbon -	- - -	6120·9
Carbon burnt with peroxide of azote at 10° - - - -	- - -	20084·2
Decomposition of peroxide of azote -	- - -	19962·9
Decomposition of water oxygenated, 1 gr. oxygen - - -	- - -	2345·4
Decomposition of oxide of silver absorbs	- - -	− 39·8
Iceland spar for CO^{2} and C to O, absorbs	- - -	−554·6
Aragonite combined gives - - -	- - -	+ 68·9
Aragonite separated absorbs - - -	- - -	−554·6
Aragonite separated after combination absorbs - - -	- - -	−485·6

CHAP. X.

ANIMAL HEAT.

630. ORGANISED bodies in general present a striking exception to the law of equalisation of temperature, since, with some rare exceptions, these bodies are never at the temperature of the medium which surrounds them. The human body, as is well known, has a permanent and invariable temperature much more elevated than that of the atmosphere. The animals of the polar regions are much warmer than the ice upon which they rest, and those which inhabit tropical climates colder in general than the air they respire. The temperature of the bodies of birds is not that of the atmosphere, nor of fishes that of the sea.

There is, therefore, in organised bodies, some proper source of heat, or rather some provision by which heat and cold can be produced at need; for the ponderable matter which composes the bodies of these creatures must, like all ponderable matter, be subject to the general law of equilibrium of temperature. It is therefore necessary to ascertain what is the temperature of organised creatures; what are the quantities of heat which they evolve in a given time to maintain this temperature; and what is the physical apparatus by which that heat is elaborated.

631. The temperature of the blood in the human species is found to be the same throughout the whole extent of the body, and is that which is indicated by a thermometer, whose bulb is placed under the tongue and held there until the mercurial column becomes stationary. This temperature is 98°·6, subject to extremely small variations, depending on health, age, and climate.

632. Dr. John Davy, Inspector of Army Hospitals, availed himself of the opportunities presented by his professional appointment, and of a voyage made by him to the East, to make an extensive and valuable series of observations on the temperature of the blood in man, in different climates, at different ages, and among different races, as well as upon the inferior animals. These observations were made between 1816 and 1820.

The first series of observations were made during a voyage from England to Ceylon, and, therefore, under exposure to very various climates and temperatures. The temperature of the blood was observed by means of a sensitive thermometer applied under the tongue near its root, with every precaution necessary to ensure accuracy. The principal results obtained are collected and arranged in the following tables : —

Table I.

633. *Showing the Temperatures of the Blood of* 13 *Individuals in different Climates.*

Age.	Air, 60°.	Air, 78°.	Air, 79·50°.	Air, 80°.
24	98·5	99	100	99·5
28	—	99·5	99·5	99·5
25	98·25	98·75	98·5	99·75
17	—	99	99	100
25	98	99	99	99·5
20	98·75	98	99·5	100
28	98·25	98·75	99	99·5
25	98	—	—	101
40	—	—	—	99·75
43	—	—	—	99
40	—	—	—	99·5
13	—	—	—	100
4	—	—	—	99·5

Table II.

634. *Showing the Temperatures of the Blood of* 6 *Individuals in different Climates.*

Age.	Air, 69°.	Air, 83°.	Air, 82°.	Air, 84°.
35	98	99	102	98·5
20	98	99	101	98
40	99	99	98·5	98
35	98	99·75	99	98
20	98	99·5	99	—
24	98	99·5	100	—

Table III.

635. *Showing the Temperatures of the Blood in the same Individual at different Hours of the Day.*

Hour.	Air.	Blood.	Sensation.
6 A.M.	60·5	98	Cool.
9	66	97·5	Cold.
1 P.M.	78	98·5	Cool.
4	79	98·5	Warm.
6	71	99	Warm.
11	69	98	Cool.

Table IV.

636. *Showing the Limits between which the Temperature of the Blood in different Races was observed to vary in India. Air,* 75° *to* 81°.

Races.	Temperature.	Races.	Temperature.
Cape Hottentots - -	96·5 to 99·5	Vaidas - - - - -	98 to 98·5
Cingalese - - - -	100 101·5	African Negroes - -	98·5 99·5
Albinoes - - - -	101 101·75	Malays - - - -	98·5 99·5
Half caste - - - -	100 102	Sepoys - - - - -	98 100
White Children - -	101 102	English - - - -	98 101
Kandians - - - -	97·5 99		

Table V.

637. *Showing the Temperature of the Blood observed in different Species of Animals.*

Name.	Air.	Temperature.	Place of Observation.
Mammalia.			
Monkey	86°	104½	Colombo.
Pangolin	80	90	—
Bat	82	100	—
Vampyre	70	100	—
Squirrel	81	102	—
Rat	80	102	—
Guinea-pig	—	102	Chatham.
Hare	80	100	Colombo.
Ichneumon	81	103	—
Jungle cat	80	99	—
Cur dog	—	103	Kandy.
Jackal	84	101	Colombo.
Cat	60	101	London.
,,	79	102	Kandy.
Felix pardus	81	102	Colombo.
Horse	80	99·5	Kandy.
Sheep	—	101 to 104	Scotland.
,,	67	103 to 104	Cape.
,,	78	104 to 105	Colombo.
Goat	78	103 to 104	Colombo.
Ox	Sumr	100	Edinburgh.
,,	80	102	Kandy.
Elk	78	103	Mount Lavinia
Hog	75	105	Doombera.
,,	80	105	Mount Lavinia
Elephant	80	99·5	Colombo.
Porpoise	72	100	Lat. N. 8° 23′ at sea.
Birds.			
Falcon	77·5	99	Colombo.
Screech-owl	60	106	London.
Jackdaw	85	107	Kandy.
Thrush	60	109	London.
Sparrow	80	108	Kandy.
Pigeon	60	108	London.
,,	78	109·5	Mount Lavinia
Jungle fowl	78	107·5	Ceylon.
,,	83	108·5	—
Common fowl	40	108·5	Edinburgh.
,,	78	110	Mount Lavinia
,,	—	108	—
Guinea fowl	—	110	—
Turkey	—	109	—
Procellaria equinoxialis	79	103·5 to 105·5	Lat. N. 2° 3′.
P. capensis	59	105·5	Lat. S. 34° 1′ at sea.
Common hen	77	110	Mount Lavinia
,, cock	77	111	—
Chicken	77	111	—
Malay cock	—	110	—
Goose	—	106 to 107	—

Name.	Air.	Temperature.	Place of Observation.
Birds.			
Duck	—	110 — 111	Mount Lav
Teal	—	108 — 109½	—
Snipe	83	98	Colombo.
Plover	—	105	Ceylon.
Peacock	83	105 — 108	Kornegall
Amphibia.			
Testudo midas	79·5	84	Lat. N. 2°
,,	80	88·5	—
,,	86	85	Colombo.
T. geometrica	61	62·5	Cape.
,,	80	87	Colombo.
Rana ventricosa	80	77	Kandy.
Common frog	60	64	Edinburg
Iguana	82	82½	Colombo.
Serpents	81½	88½	—
,,	82¼	84¼	—
Fishes.			
Shark	71¾	77	Lat. S. 8°
Bonito	78	82*	Lat. S. 1°
Trout	56	58	Edinburg
,,	56	58	L. Katrin
Eel	51	51	Chatham.
Flying-fish	77	78	Lat. N. 6°
Mollusca.			
Oyster	82	82	Mount La
Snail	76½	76 to 76½	Kandy.
Crustacea.			
Crayfish	80	79	Colombo.
Crab	72	72	Kandy.
Insects.			
Scarabæus pilularius	76	77	Kandy.
Glow-worm	73	74	—
Blatta orientalis	83	74 — 75	—
Gryllus hœmatopus ?	62	72½	Cape.
Apis ichneumonia ?	75	75	Kandy.
Papilio agamemnon	78	80	—
Scorpio afer	79	77½	—
Julus	80	78½	—

638. The conclusions deduced from these observations and experiments are, that the temperature of man, although nearly

* This was the temperature of the heart, which lies near the surface. In the deeply-seated muscles the temperature was 99.

constant, is not exactly so; that it is slightly augmented with the increased temperature of the climate to which the individual is exposed; that the temperature of the inhabitants of a warm climate is higher than those of a mild; and that the temperature of the different races of mankind is, *cæteris paribus*, nearly the same. This is the more remarkable, inasmuch as among those whose temperatures thus agree there is scarcely any condition in common except the air they breathe. Some, such as the Vaida, live almost exclusively on animal food; others, as the priests of Buddh, exclusively on vegetables; and others, as Europeans and Africans, on both.

639. Of all animals birds have the highest temperature; mammalia come next; then amphibia, fishes, and certain insects. Mollusca, crustacea, and worms stand lowest in the scale of temperature.

Experiments were made by MM. Breschet and Becquerel to ascertain the variation of the temperature of the human body in a state of health and sickness. They employed for this purpose compound thermoscopic needles, composed of two different metals, which, being exposed to a change of temperature, indicated with great sensitiveness the sensible heat by which they were affected, by means of a galvanometer on a principle similar to the electroscopic apparatus used by M. Melloni, already described (577.). The needles were adapted for use by the method of acupuncture.

640. It was found that in a state of fever the general temperature of the body sometimes rose from 1°·8 to 3°·6.

It was also ascertained, in several cases of local chronic and accidental inflammation, that the temperature of the inflamed part was a little higher than the general temperature of the body, the excess, however, never amounting to more than from 1°·8 to 3°·6.

641. It resulted from these researches that, in the dog, the arterial blood exceeds in temperature the venous by about 1°·8. It was also found that the temperature of the bodies of the inhabitants of the valley of the Rhone and those of the Great St. Bernard, both men and inferior animals, were the same.

642. A series of experiments was made by Lavoisier and Laplace to determine, by means of their calorimeter, already described, the quantity of heat developed in a given time by various animals; but more recently much more extensive researches in this department were made by Dulong, which have produced important results. In these experiments the animal under examination was shut up in a copper cage sufficiently capacious to be left at ease, and being submerged in a glass vessel of water, the air necessary for respiration was supplied and measured by a gasometer, while the products of respiration were carried away through the water,

to which they imparted their heat, and were afterwards collected and analysed. Each experiment was continued for two hours. After the proper corrections had been applied, the heat developed by the animal was calculated by the heat imparted to the water.

Dulong determined these thermal quantities with great precision for numerous animals of different species, young and adult, carnivorous and frugivorous. The animals, during the experiment, being subject neither to inconvenience nor fatigue, it might be assumed the heat they lost was equal to that which they reproduced. On analysing the products of respiration, it was found that they were changed as air is which has undergone combustion. The oxygen of the atmospheric air which was introduced into the cage was in fact combined with carbon, and formed carbonic acid. So far, therefore, as concerned this point, a real combustion may be considered as having taken place in the lungs. Thus much was inferred in general as to the source of animal heat from the discoveries of Lavoisier.

643. It remained, however, to verify this discovery by showing that the exact quantity of heat evolved in the animal system could be accounted for by the chemical phenomena manifested in respiration; and this Dulong accomplished.

After having determined the quantity of heat lost by the animal, he calculated the quantity of heat produced by respiration. The air which was furnished to the animal was measured by the gasometer, and the changes which it suffered were taken into account by analysing the products of combustion discharged through the water from the cage. These products were as follows:—

1. The vapour of water.
2. Carbonic acid.
3. Azote.

The vapour of water analysed gave a certain quantity of oxygen and hydrogen, the carbonic acid a certain quantity of carbon and oxygen, and the azote was sensibly equal to the quantity of that gas contained in the atmospheric air supplied to the animal. It followed that the oxygen of the atmospheric air which had been supplied combined in the lungs partly with carbon and partly with hydrogen, producing by respiration carbonic acid and the vapour of the water, being exactly the products resulting from the combustion of a lamp or candle. Now the quantity of heat produced by the combustion of given quantities of carbon and hydrogen being taken and compared with the quantity of animal heat developed, as given by the heat imparted to the water, was found exactly to correspond; and thus it followed that the source of animal heat is the same as the source of heat in the common process of combustion.

When these researches were first made, it appeared that the quantity of heat actually developed in the animal system exceeded the quantity computed to result from the chemical change which the air suffered in respiration, and it was consequently inferred that the balance was due to a certain nervous energy or original source of heat existing in the animal organisation independently of the common laws of physics. Dulong, however, had the sagacity to perceive that the phenomenon admitted of a more satisfactory and simple explanation, and succeeded at length in showing that the difference which had appeared between the quantity of heat developed in respiration, and the quantity due to the chemical changes which the air suffered in this process, was accounted for by the fact that the quantity of heat developed in the combustion of hydrogen and oxygen had been under estimated, and that when the correct coefficient was applied, the quantity of heat due to chemical changes suffered by the air in respiration was exactly equal to the quantity of heat developed in the animal system.

CHAP. XI.

THE SENSATION OF HEAT.

644. **The senses fallacious.**— The senses, though appealed to by the whole world as the most unerring witnesses of the physical qualities of bodies, are found, when submitted to the severe scrutiny of the understanding, not only not the best sources of exact information as to the qualities or degrees of the physical principles by which they are severally affected, but the most fallible guides that can be selected, often informing us of a quality which is absent, and of the absence of one which is present.

Nor should this be any matter of surprise. Our Maker, in giving us organs of sense, did not design to supply us with philosophical instruments. The eye, the ear, and the touch, though admirably adapted to serve our purposes, are not severally a telescope, a monochord, and a thermometer. An eye which would enable us to see the inhabitants of a planet would ill requite its owner for that ruder power which guides him through the town he inhabits, and enables him to recognise the friends who surround him. The comparison of the instruments which are adapted for the uses of commerce and domestic economy with those destined for scientific purposes supplies an appropriate illustration of these

views. The delicate balance used by the chemist in determining the analysis of the bodies upon which he is engaged would, by reason of its very perfection and sensibility, be utterly useless in the hands of the merchant or the housewife. Each class of instruments has, however, its peculiar use, and is adapted to give indications with that degree of accuracy which is necessary, and required for the purposes to which it is applied.

645. The touch is the sense by which we acquire a perception of heat. It is evident, nevertheless, that it cannot inform us of the quantity of heat which a body contains, much less of the relative quantities contained in any two bodies. In the first place, the touch is not affected by heat which exists in the latent state. Ice-cold water and ice itself have the same degree of cold to the touch, and yet it has been proved that the former contains 140° of heat more than the latter.

646. But it may be said that even the thermometer does not in this case indicate the presence of the excess of heat in the liquid. The sense of feeling will, however, be found almost as fallacious as regards the temperature of bodies; for it is easy to show that the sense of warmth depends as much upon the condition of the part of the body which touches or is surrounded by the warm or cold medium, as on the temperature of that medium itself.

If the two hands be plunged, one in water at the temperature of 200° and the other in snow, and being held there for a certain time are transferred to water of the intermediate temperature of 100°, this water will appear warm to one hand and cold to the other; warm to the hand which had been plunged in the snow, and cold to the hand which had been plunged in the water at 200°.

If on a hot day in summer we descend into a deep cave, it will feel cold; if we descend into the same deep cave on a frosty day in winter, it will feel warm; yet a thermometer in this case will prove that in the winter and in the summer it has exactly the same temperature.

647. These apparent anomalies are easily explained. The sensation of heat is relative. When the body has been exposed to a high temperature, a medium which has a lower temperature will feel cold, and when it has been exposed to a low temperature it will feel warm.

If in a room raised to a high temperature, as in a vapour or hot air bath, we touch with the hand different objects, they will appear to have very different temperatures; a woollen carpet will feel cold, marble slabs warm, and metal objects very hot. If, on the other hand, we are in a room at a very low temperature, all these properties will be reversed; the carpet will feel warm, the marble slabs cold, and the metallic objects colder still.

These effects are easily explained. A woollen carpet is a nonconductor of heat. When surrounding objects are at a more elevated temperature than that of the body, the woollen carpet partaking in this temperature will, when touched, feel cool, because, being a nonconductor of heat, the heat which pervades it does not pass freely to the part of the body which touches it. A marble slab being a better conductor, and a metallic object a still better, the heat will pass from them more freely to the part of the body which touches them, and they accordingly appear hotter.

But if the room be at a temperature much lower than the body, then when we touch the woollen carpet the heat does not pass from our body to the carpet because it is a nonconductor, and as we do not lose heat, the carpet feels warm; but when we touch the marble, and still more a metallic object, the heat passes more and more freely from our body to these objects, and being sensible of a loss of heat more or less rapid, we feel cold.

648. When we plunge in a cold bath, we are accustomed to imagine that the water is colder than the air and surrounding objects; but if a thermometer be immersed in the water, and another suspended in the air, they will indicate the same temperature. The apparent cold of the water arises from the fact that it abstracts from our bodies heat more rapidly than air does, being a denser fluid, and a greater number of particles of it coming into contact at once with the surface of the body. A linen feels colder than a cotton, and a cotton colder than a flannel shirt, yet all the three are at exactly the same temperature. Linen is a better conductor of heat than cotton, and cotton than flannel, and consequently, the heat passes more freely through the first than the second, and through the second than the third.

The sheets of a bed feel cold, and the blankets warm, and yet they are of the same temperature,— a fact which is explained in the same manner.

The air which is impelled against a lady's face by her fan feels cold, while the same air at rest around her feels warm; yet it is certain that the temperature of the air is not lowered by being put in motion. The apparent coolness is explained in this case by a slight evaporation, which is effected upon the skin by the motion given to the air by the fan.

649. Some of the feats performed by quacks and fire-eaters in exposing their bodies to fierce temperatures may be easily explained upon this principle. When a man goes into an oven raised to a very high temperature, he takes care to place under his feet a cloth or mat made of wool or other nonconducting substance upon which he may stand with impunity at the proposed temperature. His body is surrounded with air raised, it is true, to a very high

temperature, but the extreme tenuity of this fluid causes all that portion of it in contact with the body at any given time to produce but a slight effect in communicating heat. The exhibitor always takes care to be out of contact with any good conducting substance, and when he exhibits the effect produced by the oven in which he is enclosed upon other objects, he takes as much care to place them in a situation very different from that which he himself has occupied. He exposes them to the effect of metal or other good conductors.

Meat has been exhibited dressed in the apartment with the exhibitor. A metal surface is in this case provided, and probably raised to a much higher temperature than the atmosphere in which the exhibitor is placed.

INDEX.

NOTE. — This Index refers to the numbers of the paragraphs, and not to the pages.

D.

E.

D.

G.

H.

I.

THE END.

LONDON:
Printed by SPOTTISWOODE and Co.,
New-street-Square.





